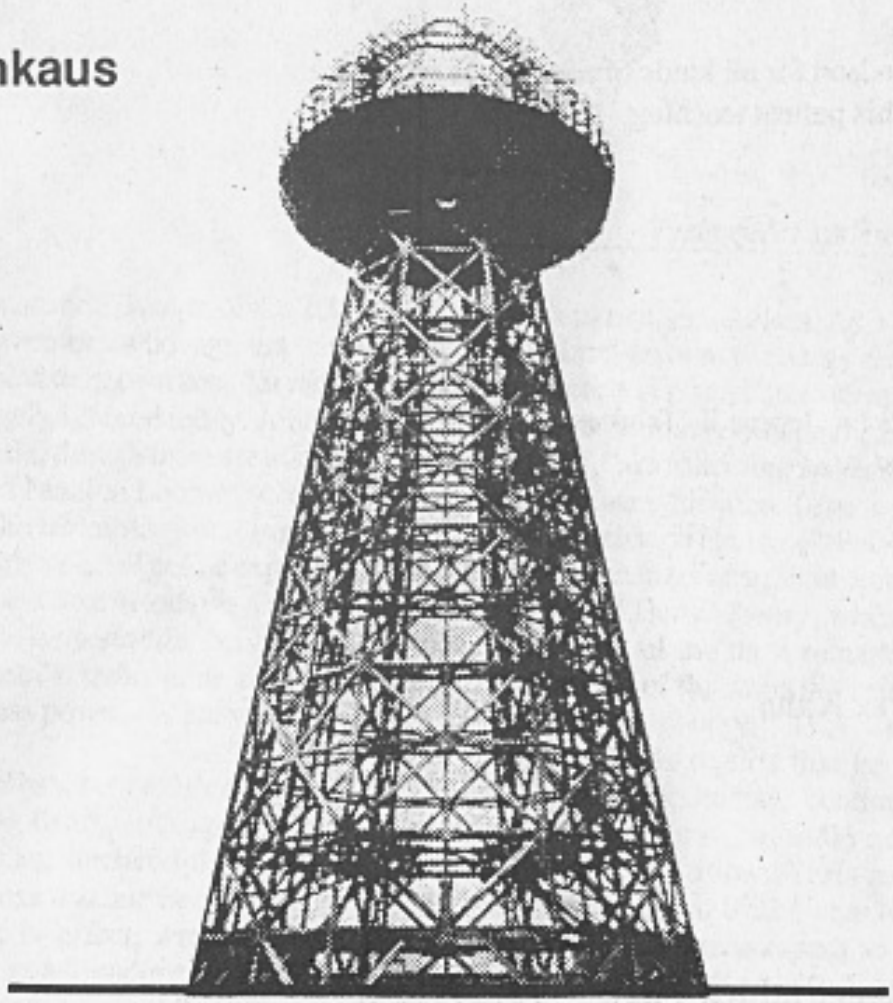
RADIO TESLA

the secret of Tesla's radio and wireless power

by George Trinkaus



In clear English, 66 illustrations, and a minimum of math, this booklet details the peculiar radio technology of Nikola Tesla. Early elemental radio devices like Tesla's are fascinating and worthy of study because they remind us that powerful radio technologies can be so simple and accessible. Tesla's transmitters produced high-voltage, sudden-pulse disturbances conducted through the earth at low frequencies. His radio is as taboo in official science as his wireless power, which works on the very same principles. Tesla said the radio physics of Hertz, still in vogue, was an "abberation," a "fiction." Modern radio took a lot from Tesla, but what did it ignore? Also in these pages: spark reconsidered, grounding rediscovered, low frequency revived, lament on solid state, underground radio, license-free radio, the suppression of amateur radio, carrier-current radio, radio-free energy...

$7.75

"Oscillations of low frequency are ever so much more effective in transmission." — Tesla, page 10

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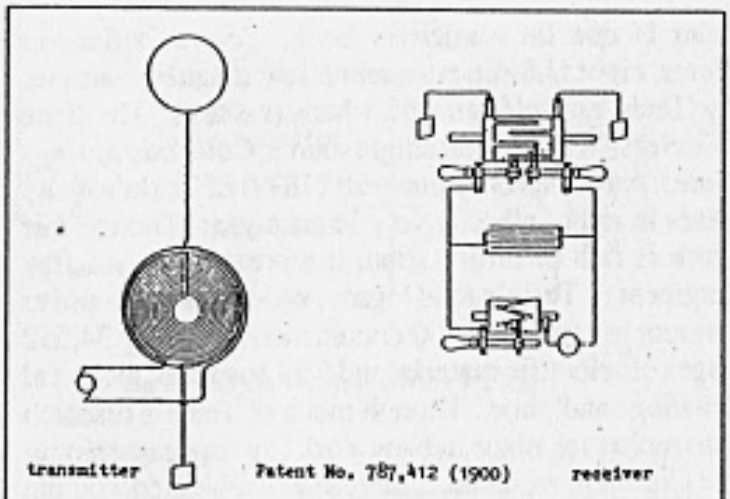
Introduction



Tesla radio system

When radio was born around the turn of the 20th century, various inventors, who are not celebrated today, created their own peculiar radio technologies, which are largely ignored today. Among these inventors is Nikola Tesla, though there are others, like Nathan Stubblefield and Mahlon Loomis, who are even more obscure. The radio technology that is peculiar to Tesla, though it got a few years of public exposure in its time, gets even less acceptance in today's technology than Tesla's disk turbine, his tesla coil, or his high-frequency lighting, and Tesla's radio is as taboo in official science as his wireless power, which works on the very same principles.

In 1943, only a few months after Tesla's death, the U.S. Supreme Court, yielding finally to the pressure of a suit fought over many years, declared that Tesla's radio patents were among those that had been infringed upon by Marconi and thus, in effect, wrote into the official record Tesla's status as a founder of radio. This was a purely symbolic victory, for Tesla's radio was suppressed, and the technology that developed is distinctly different in many essential respects.

During the period of radio's most rapid growth (1915-1940), Tesla watched quietly from the sidelines, for by this time he had fallen out of favor with the media, or rather with the establishment that controls it. Still, some of his comments have made it into the published record. In 1927 he said that broadcasting "is now carried out with unfit apparatus and on a commercially defective plan." Of radio technology generally Tesla said in 1932 that "the transmitting and receiving apparatus is ill-conceived and not well adapted for selection. The transmitter generates several systems of waves, all of which, except one, are useless. As a consequence only an infinitesimal amount of energy reaches the receiver, and dependence is placed on extreme amplification."

"Radio experimenters of this age," Tesla said of the hams of 1934, "are following ancient theories." By this he meant backward theories. Tesla's favorite backward theorist was Heinrich Hertz, who saw the phenomenon of radio as some kind of straight-line radiation akin to light. Tesla said Hertz' theory, which is still in vogue today, was "one of the most remarkable and inexplicable aberrations of the scientific mind which has ever been recorded in history." This was not a reckless statement, for Tesla reports that he had carefully reviewed Hertz' experiments, conducted comparative tests with his own brand of radio and had come to a different set of conclusions. Tesla said, "I considered this so important that in 1892 I went to Bonn, Germany to confer with Dr. Hertz in regard to my observations. He seemed disappointed to such a degree that I regretted my trip and parted from him sorrowfully." Tesla made subsequent tests in 1900 with the same results and kept abreast of articles on Hertzian radio-telegraphy, which, he said, always impressed him "like works of fiction."

suppressed information

In this book I attempt to break down Tesla's radio into a set of specific principles and to survey the whole of radio technology from Tesla's perspective. While I have studied some out-of-print literature, much of my information comes from reprints still available. These titles I cite at a chapter's end together with addresses for ordering. (Addresses given on first mention only.)

For the core material on Tesla, what you have in

print is one fat hardcover book, *Colorado Springs Notes*, eight U.S. patents, and a few magazine articles by Tesla himself, one of which is titled "The True Wireless." The biggest single source, *Colorado Springs Notes*, embraces only one year (1899) of Tesla's many years in radio, albeit a very intense year. Though this work is rich in information, it represents only a tiny fragment of Tesla's total legacy, which has been said to amount to some 100,000 documents, including 34,552 pages of scientific material and 5,297 pages of technical drawings and plans. Though much of Tesla's research into radio took place in New York City in years prior to his Colorado adventure, there is no published volume called "New York Notes."

Colorado Springs Notes itself has a bizarre publishing history. Tesla's papers, confiscated by the U.S. government upon his death, surfaced years later in a Tesla Museum in Belgrade, Yugoslavia, or at least a large chunk of the expropriated material did. When the Museum, thirty or so years after Tesla's death, published the Colorado fragment, it did so in Serbo-Croatian, a curious choice since Tesla, though of Serbian origin, wrote these notes in English. What the Museum published as *Colorado Springs Notes* in 1978 (under the imprint NoLit) had been translated back into English from the Serbo-Croatian. The translator, in his appended notes, tends to discredit Tesla's version of radio. The discrepancies between the original and the translation have prompted a study by Tesla scholar John Ratzlaff called *Serbo-Croatian Diary Comparisons*.

These frustrations noted, you still have to be grateful for the relatively abundant documentation of Tesla's radio relative to what you would find in print on any other deviant radio pioneer, such as Loomis or Stubblefield.

To put Tesla in perspective, I have also read extensively in the literature of conventional radio, and, by way of grounding this information, have invested perhaps an inordinate amount of time in designing, building, and experimenting with elemental transmitters and receivers, a couple of which are illustrated in this book.

Tesla's radio principles

Tesla believed that radio was conduction, not radiation. A radio transmitter should put out high voltage delivered in pulses sharp and sudden. Tesla's radio was grounded rather than aerial. He saw radio as most potent in the lower frequencies. For both transmitting and receiving, the magnifying of effects, he believed, should be achieved with resonance and capacitive discharge rather than amplifier stages. He believed radio was a disturbance of a pervasive medium called the ether. Rather than a radiating antenna, he employed an aerial capacity. Tesla's radio inventions, like his others, show a striving for simplicity rather than complexity. He eschewed the miniaturization fashionable today, conducting his experiments on a fearless scale. Fundamental to resonant tuning was Tesla's quarter-wave principle. Tesla planned, promoted, and began construction of a World System of radio founded on these principles.

On these same transmitting principles, and with about the same equipment, Tesla experimented with his wireless power. This was a radio-like system that was to be a successor to the wired grid, which was built on Tesla's own 60-cycle alternating-current patents. Tesla's wireless power system (also patented) was designed to deliver by means of earth-electrical vibration power sufficient for industrial demands.

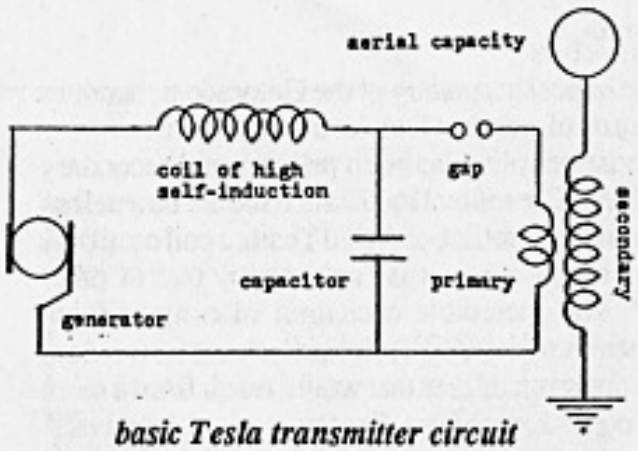
Tesla boasts of the simplicity of his wireless-power receiving system: "Any person skilled in the mechanical and electrical arts can utilize to advantage the practical applications of the system," by which he means that any person so skilled can construct the apparatus, receive the energy, and put it to use. Thus Tesla's system short-circuits the techno-priesthood, inviting suppression.

Tesla's wireless power has never been duplicated. Tesla is on record as saying that he lit up 10,000 watts worth of Edison bulbs wirelessly 26 miles from his magnifying transmitter at Colorado Springs, but if Tesla wrote an entry on this remarkable experiment, it is not to be found in the English version of the published *Notes*. Whatever the viability of Tesla's wireless power, his conviction that such a thing was possible testifies to his belief in the special power of his peculiar radio technology.

for more information

Tesla's **Colorado Springs Notes** (No-Lit) is distributed by Twenty First Century Books (P.O. Box 2001, Breckenridge, CO 80424, www.tfcbooks.com) as are John Ratzlaff's **Complete Patents** of Tesla, **Serbo-Croation Diary Comparisons**, and Ratzlaffs' **Tesla Bibliography**.

1. High Voltage, Sudden Pulse



basic Tesla transmitter circuit

Tesla-style radio transmitting applies high electromotive force to the aerial-ground system – "hundred thousands or millions of volts," said Tesla. These extraordinary-sounding pressures can be achieved using the tesla coil, and fact is that Tesla's transmitters were tesla coils.

The tesla coil, with the addition of a resonant third coil and a few other alterations, becomes Tesla's magnifying transmitter, which Tesla boasted "would enable the obtainment of practically any emf, the limits being so far remote that I would not hesitate to produce sparks thousands of feet long in this manner." In Tesla radio you are happening only when your aerial glows blue.

In modern transmitters potentials in the hundreds of thousands, much less millions, of volts are unheard-of. Rarely does the voltage anywhere in vacuum-tube transmitter circuits exceed ten thousand and is usually under 1500. Antenna voltage rarely exceeds 1000. In calculating the performance of a modern transmitter, focus is on antenna current, not voltage.

sudden pulse

In addition to the high voltage, Tesla-style transmission requires sudden pulsings, in Tesla's words, "an immense rate of momentary energy delivery." This also comes easily to the tesla coil transmitter, driven as it is by the sudden capacitive discharges of Tesla's spark-gap oscillator.

Tesla's transmitters

"With electromotive impulses not greatly exceeding 15 to 20 million volts, the energy of many thousands of horsepower may be transmitted over vast distances, measured by many hundreds and even thousands of miles." So writes Tesla in a basic radio and wireless-power patent. Among the uses for this electromotive energy Tesla cites the transmission of "intelligible messages to great distances," power for "industrial purposes," the production of nitric acid and fertilizer by electrifying nitrogen in the atmosphere, and the illumination of "upper strata of air," this last item referring to Tesla's outrageous scheme to light up areas of the planet at night by beaming oscillating electric energy into the sky.

"It is a form of oscillator of great simplicity," Tesla wrote. "A coil of high self-induction is connected in series with a condenser, and across the condenser is placed a break generally in series with the primary of the coil. Very sudden discharges are produced when using a fine stream of electrolyte or mercury to effect short circuit," says Tesla, referring to one of his patented circuit controllers.

engineering

The engineering of the Tesla transmitter is the engineering of the tesla coil, and I offer, as supplement to my booklet on the subject, the following guidelines from Tesla's patents and Colorado notes:

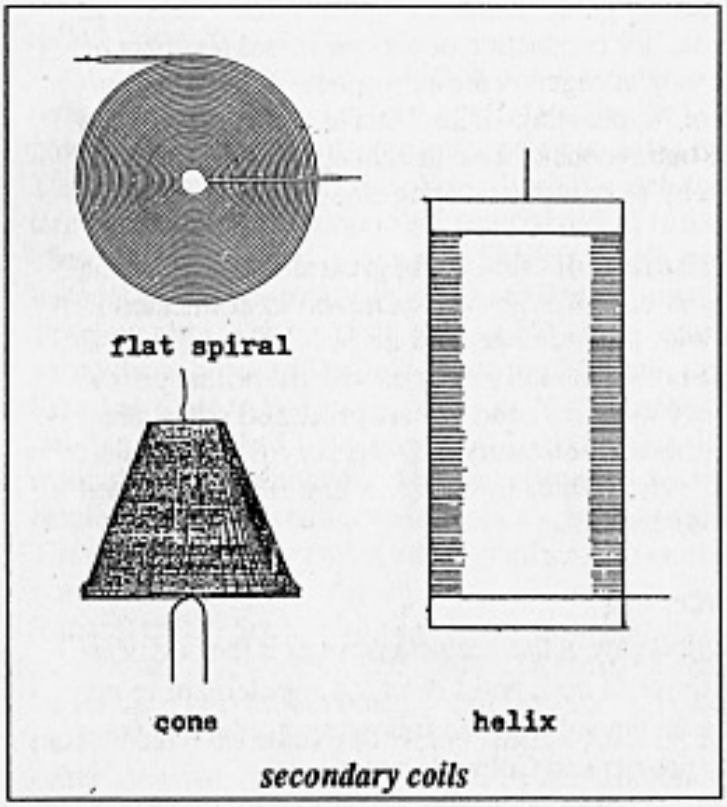
The primary coil's inductance, and its resistance, should be as low as possible. Just one turn of heavy double cable sufficed for the 51-foot diameter primary of Tesla's Colorado transmitter, and the coil with which Tesla demonstrated wireless before the patent examiners, a coil with a flat spiral secondary, had a primary of a single turn.

The primary and secondary should have equal weights of metal. This principle helps determine the thickness of the primary conductor.

Of the secondary, Tesla wrote that its resistance, too, should be as low as possible, but the self-induction should be as high as possible. The flat spiral secondary of the coil mentioned above had 50 turns of number 10

wire. The helical secondary of the Colorado transmitter had 24 turns of number 8 on its 51-foot diameter.

A loose coupling between primary and secondary is desirable. "The mutual inductance should be small so as to permit free oscillation," said Tesla; a coil oscillates most vigorously when it is "inductively free of other circuits." The incredible excitation of a magnifying transmitter's tertiary coil Tesla attributes to its freedom from the damping effects that would result from a more closely coupled secondary. The tertiary, or "extra coil," as Tesla called it, can be located some distance from the coil stimulating it. Within the Colorado transmitter's

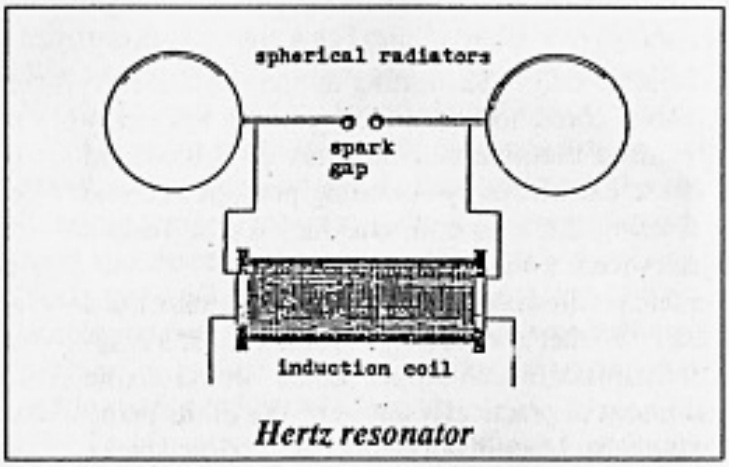


secondary coils

51-foot diameter primary-secondary coil system, Tesla would set down a tertiary, not necessarily centered. One Colorado photo shows several of these extra coils, ranging in diameters from seven inches to eight feet, placed here and there within the 51-foot enclosure, each spouting sparks.

Loose coupling for a more free and swinging oscillation is an engineering objective behind the flat-spiral secondary design. As the coil spirals in, turns become more and more remote from the primary and its inertial influence. Also, since the secondary takes on higher voltage as it spirals inward, the outer turns nearer the primary are at relatively low potential, and this helps to thwart arcing between the coils. A cone-shaped secondary offers similar advantages and is also considered superior to the customary helical.

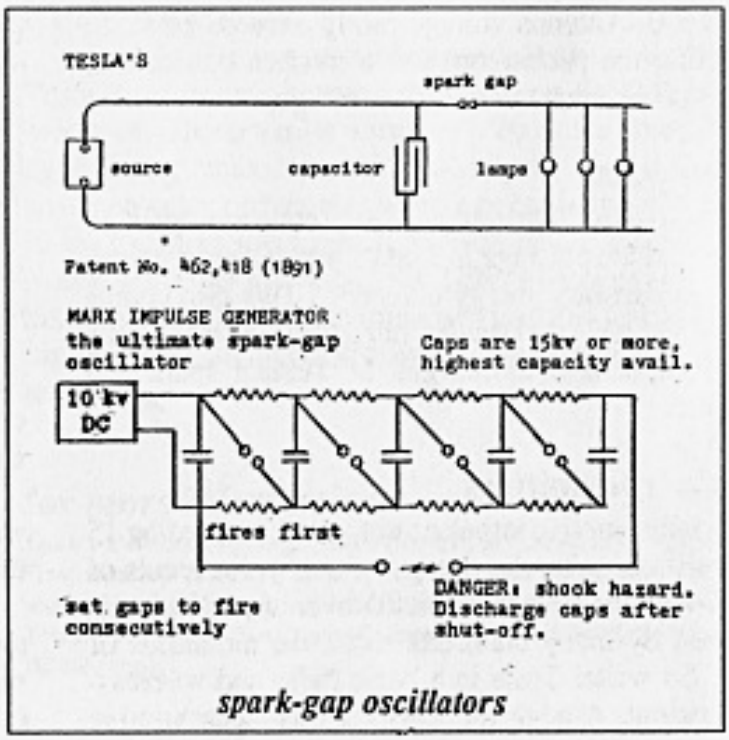
The magnifying effect of the interacting coils, Tesla said, is "directly proportionate to the inductance and frequency and inversely to the resistance of the secondary system." This need for low resistance invites the builder to consider conductors superior to conventional copper wire. A video from Borderland Sciences



Hertz resonator

demonstrates a Tesla-style transmitter with a flat-spiral secondary made of silver-teflon coaxial cable; the shielding is the conductor. The same coil has a primary of bronze strap.

Tesla tuned his transmitters for "maximum rise of



spark-gap oscillators

emf on the excited system," as indicated by a small incandescent bulb connected in a single loop around the final coil. Tuning was aided by a regulating coil and by an adjustable spark gap in the ground circuit or by a gap shunting part of the secondary. He observed that "the tuning is remarkably exact, 1/8 turn of the self-induction box reducing the effect very much." He said, "It becomes easy to locate the maximum rise within one-quarter of one percent." He described his transmitter's tuning as "very sharp."

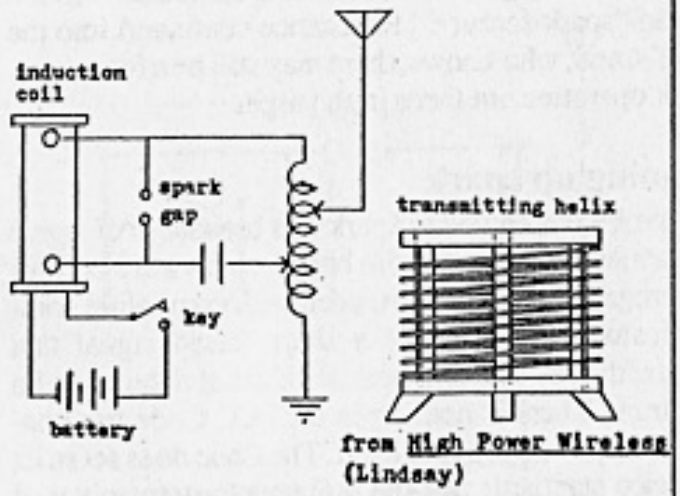
spark

Spark radio is high-voltage, sudden-pulse. Spark is as old as radio itself. Radio was supposedly discovered by somebody wondering about spark noises in a telephone. Hertz' experiments used spark. The induction coil with spark gap is the first radio transmitter. The next advance put a capacitor in the circuit, as in Tesla's spark-gap oscillator. This Tesla invented not for radio but for an early high-frequency lighting system. For radio, Tesla used his all-purpose oscillator, the tesla coil.

As radio moved into the future, leaving Tesla behind, the spark transmitter that came into general use was not a tesla coil but a truncated version in which the magical resonant secondary was lopped off. The power supply was an induction coil which one could build or buy. One manufacturer advertised eleven models providing sparks from 1/4 inch to 8 inches. Antenna and ground were connected to a primary-like helical coil called a transmitting helix. The rarity of true tesla-coil transmitters in the literature suggests that this potent oscillator may have been a well-kept secret even in the spark era.

"spark forever"

"Using spark allows obtaining of great suddenness," said Tesla. No modern tube or semiconductor can match disruptive discharge for rapid switching of high energy without blowing apart. The history of radio reports that operators were satisfied with spark. "The pervading spirit was one of complete complacency with regard to the technical status of the art," according to one historian. A 250-watt spark set went 300-400 miles, and with spark that power was easy to come by. The circuitry is simple, the parts easy to find even today for those in the know about tesla-coil building. If you needed to throw together a telegraphic radio signalling device in a pinch,



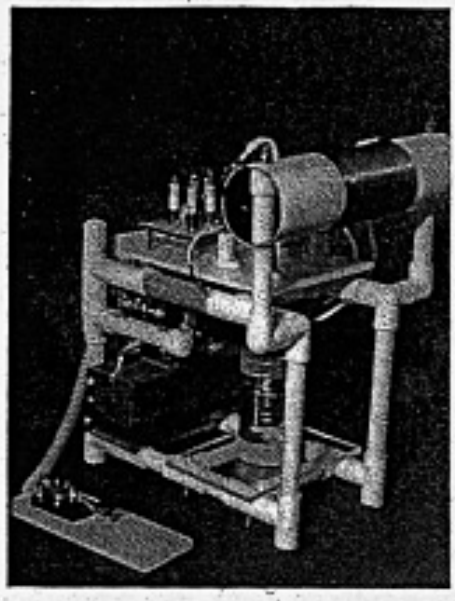
spark-gap transmitter with helix

spark might be the way to go, and even voice modulation is possible, as we shall see.

The sudden-pulse spark-gap oscillator could be used to drive a microwave cavity resonator (page 7).

Could a self-powered spark transmitter be created from a static machine? (Also page 7)

Radio operators, both commercial and amateur, resisted mightily the movement to suppress spark and replace it with tube oscillators, which they saw as costly, complex, and relatively ineffectual. The anti-spark movement was imposed from above by industry and government. Imprinted on some of the QSL cards



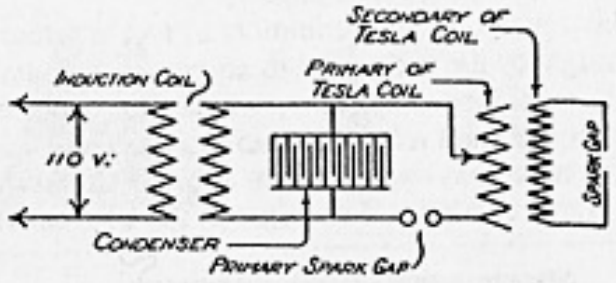
author's experimental spark transmitter

hams sent through the post to confirm contact was the slogan "spark forever." Resistance continued into the 1930's, and, who knows, there may still be a few covert spark operators out there in the night.

cleaning up spark

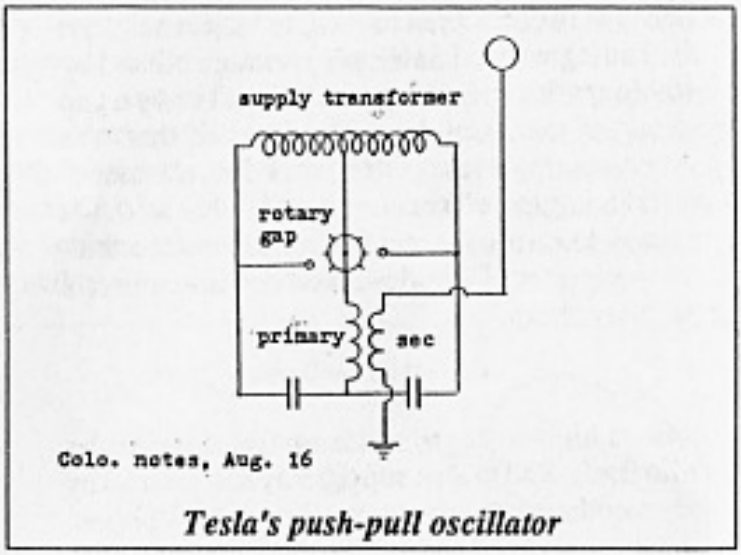
The problem imputed to spark was broadness of signal and harmonic noise in radio bands which were becoming progressively more crowded with competing communicators. Desired was a sharp, clean signal that occupied only the thinnest slice of the busy radio spectrum. There is nothing in the FCC Code for amateurs that prohibits spark itself. The Code does set strict emission standards that the rudimentary transmitter of the spark era had trouble conforming to.

The common historical impression is that spark transmitters were uniformly and inevitably crude and



tesla-coil transmitter (1910)

that the new vacuum-tube transmitters, using feedback principles of oscillation, came along like white knights and cleaned up the spectrum. Fact is, though, that toward the end of the spark era transmitters using evolved spark technologies were developed, manufactured in numbers, and saw long service on land and sea, sharing the bands with the incoming tube (and arc) transmitters. Although any spark transmitter, no matter how sophisticated, dissipated some of its power in harmonics, these advanced spark rigs produced relatively clean and narrow fundamental signals and the smooth, damped, "continuous waves" boasted by the

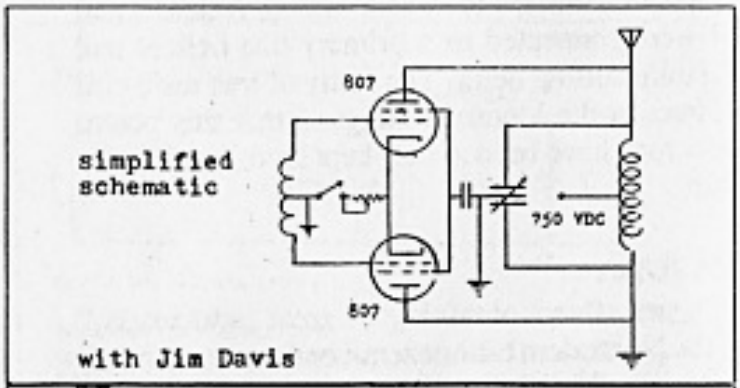


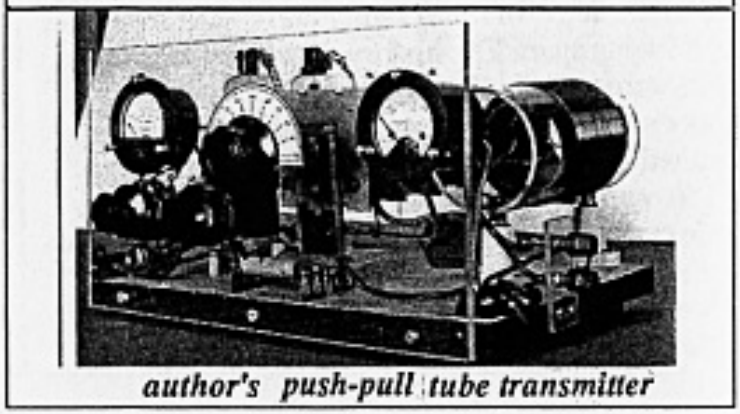
Tesla's push-pull oscillator

promoters of the new tube transmitters. Even after ships were routinely equipped with tube rigs, radio operators insisted on keeping on board as auxiliaries their old reliable units with spark.

The engineering of superior spark transmitting focused on improving the quenching (shutting off) of the gap: the technology of airtight series gaps, magnetic blow-outs, and rotary gaps. Perfecting of the spark gap got a lot of attention from Tesla, and perhaps his patents were studied by radio engineers, but not necessarily.

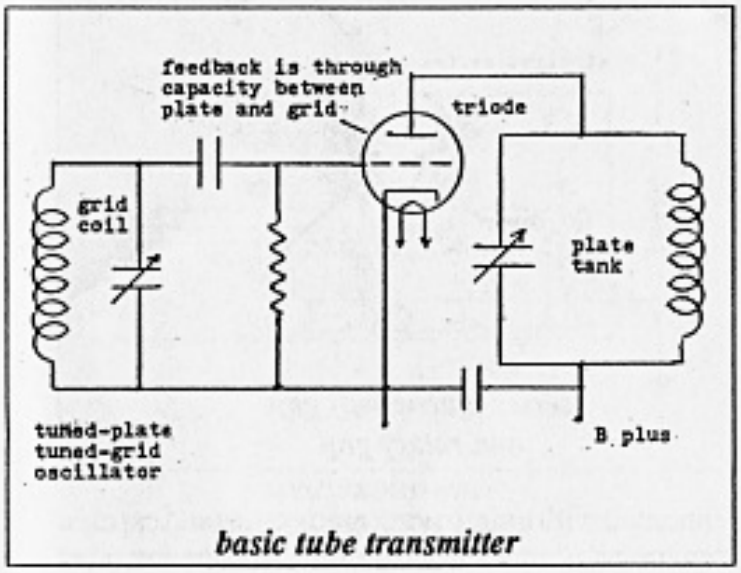
Tesla anticipated the push-pull circuit common in





author's push-pull tube transmitter

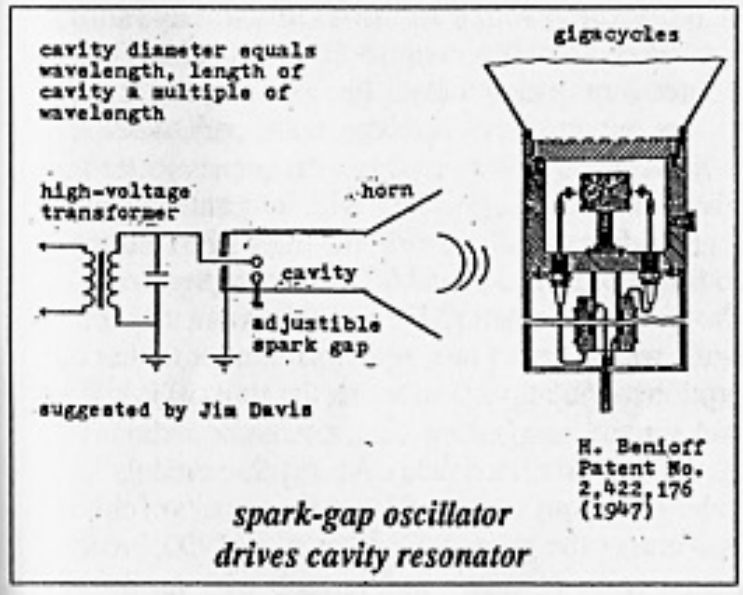
amplifiers and transmitters. Tesla ultimately replaced the spark gap altogether and achieved disruptive discharge with ingenious high-energy mechanical "breaks," including rotary mercury switches and mercury jets. Tesla said that his transmitters produced continuous



basic tube transmitter

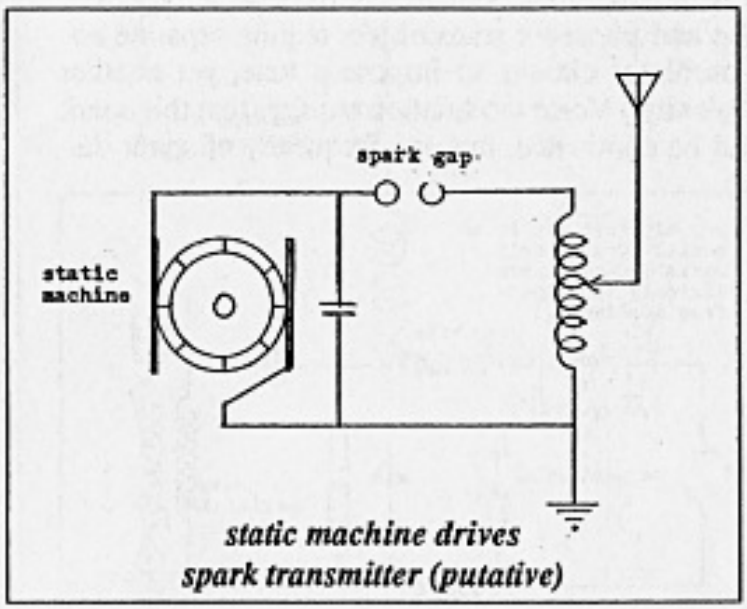
waves. Evolved spark transmitters used synchronous rotary gaps which coordinated the charging rhythm of the capacitor with the frequency.

A feature of Tesla's magnifying transmitter design that discourages undamped waves is the single-turn



spark-gap oscillator drives cavity resonator

primary. This reduces the induction of the primary circuit so that unwanted oscillation cannot occur there. The same provision shows up in the only magnifying transmitter circuit I have seen in radio outside of Tesla's.



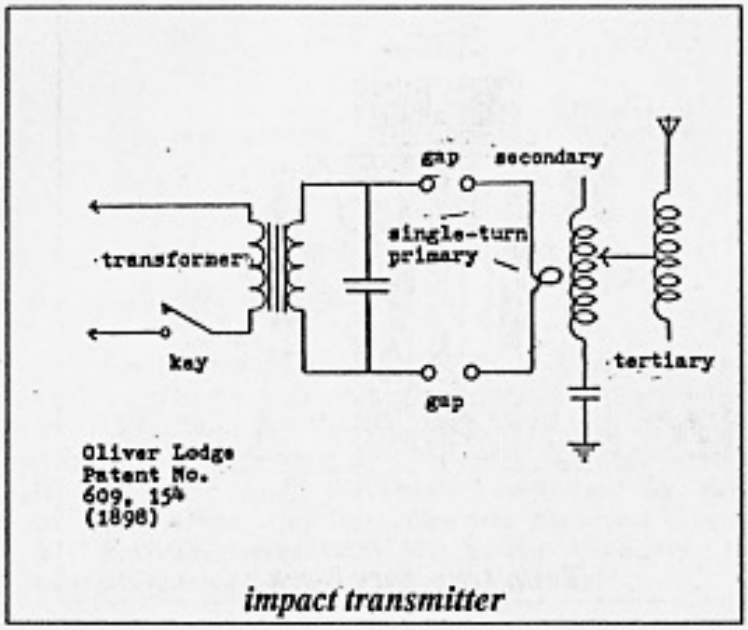
static machine drives spark transmitter (putative)

Called the impact transmitter, this circuit from the spark era featured quenched gaps in tandem. The name belies an understanding of Tesla-style sudden-pulse transmitting. Knowledge of the impact transmitter, patented by Oliver Lodge, was never widely circulated to the public and remained a secret.

Can you modulate spark?

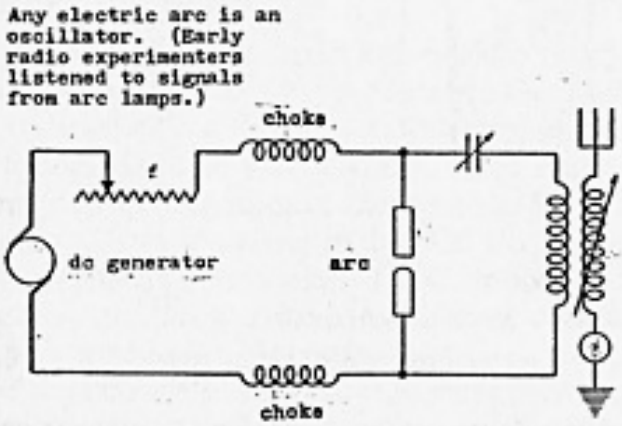
The general impression is that spark is strictly telegraphic, but, fact is, spark transmitters can be modulated.

For telegraphy, tone modulation is inherent in spark, the tone being determined by the frequency of the gap. Rotary and series gaps produce characteristic tones



impact transmitter

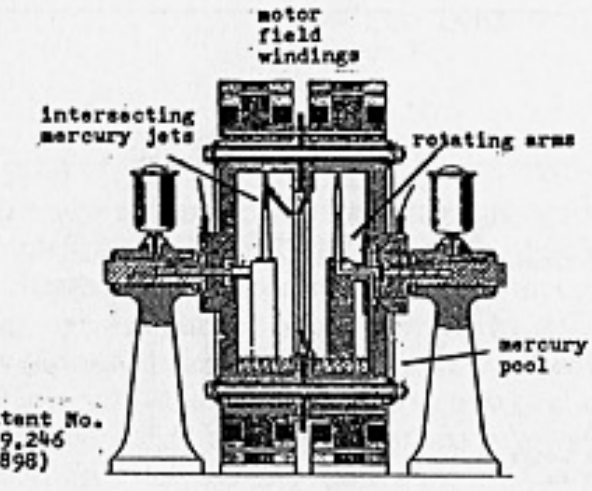
that help telegraphic signals cut through static noise. (Tube and transistor transmitters require separate audio-oscillator circuits to impose a tone, yet another complexity.) Voice modulation requires that this spark sound be eliminated, that the frequency of spark dis-


Any electric arc is an oscillator. (Early radio experimenters listened to signals from arc lamps.)
choke
dc generator
arc
choke

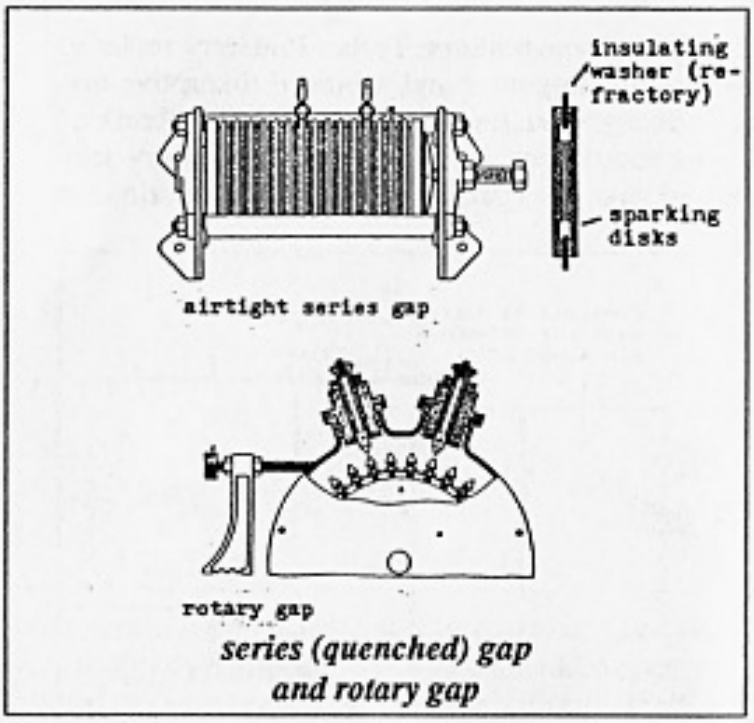
arc transmitter

charges be raised to at least 5000 sparks per second. As early as 1900, Reginald Fessenden achieved bona-fide radio telephony with a spark transmitter. He probably used a very simple and now-forgotten method known as absorption.

A precedent for absorption modulation is to be found in the technology of alternator transmitters. Tesla, the inventor of the ac generator, or alternator, had



Tesla's mercury break

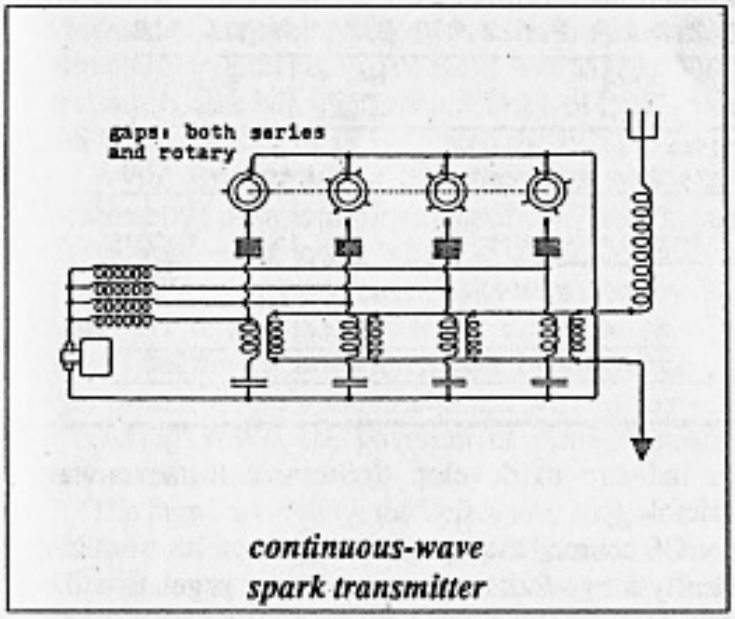


series (quenched) gap and rotary gap

experimented with units having many poles and capable of frequencies of up to 20 or 30 kc. These he intended to use not for radio but for his high-frequency lighting. Tesla abandoned the alternator early on in his experimenting because of its frequency limitations and developed his spark-gap oscillator and tesla coil for his lighting. Ironically, it was an alternator quite similar to Tesla's that became the first overseas radio transmitter. Fessenden developed a 50-kilowatt dynamo. Alexanderson scaled this up to 200 kilowatts. These huge alternators (they looked like power-plant dynamos) were put into service parallel with spark. Alternator radio necessarily remained low-frequency (often so low that voice was not possible) with long antennas and deep groundings. Unlike spark, the high-RPM alternator could not be turned on and off for telegraphy. So how did they key an alternator? The solution was a magnetic shut-off, which works on a principle similar to that of absorption modulation. Notice that the shut-off is in the ground circuit, suggesting that alternator radio was construed as a grounded radio. Absorption modulation for radio-telephony was installed in the circuits of either the antenna or the ground. Fessenden, in 1906, broadcast a program of music and speech with an 80 kc alternator.

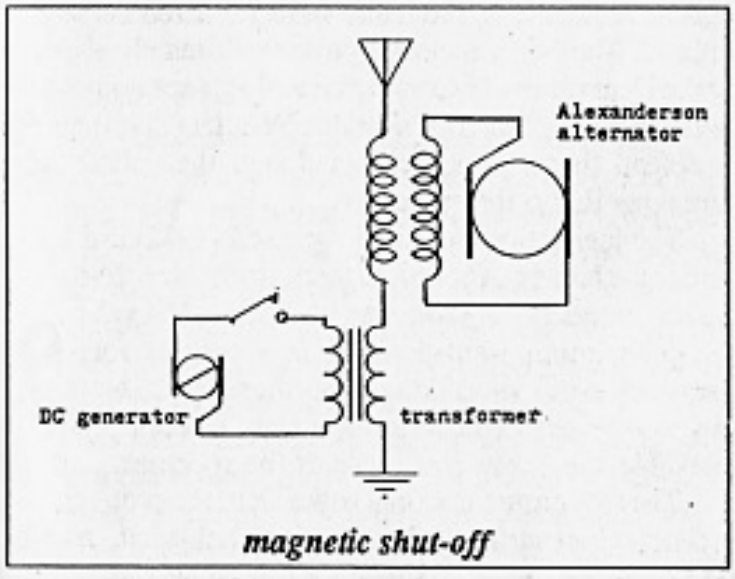
In vacuum-tube transmitting, expensive high-power audio amplifiers are necessary for plate modulation, the respectable mode; grid- and screen-modulation also

require audio amplifiers, though of lesser power. The inexpensiveness and simplicity of absorption modulation tempts experimenters who seek a simpler radio technology. I have seen the method described as "crude" in a 1924 radio book where it pops up, but no specifics

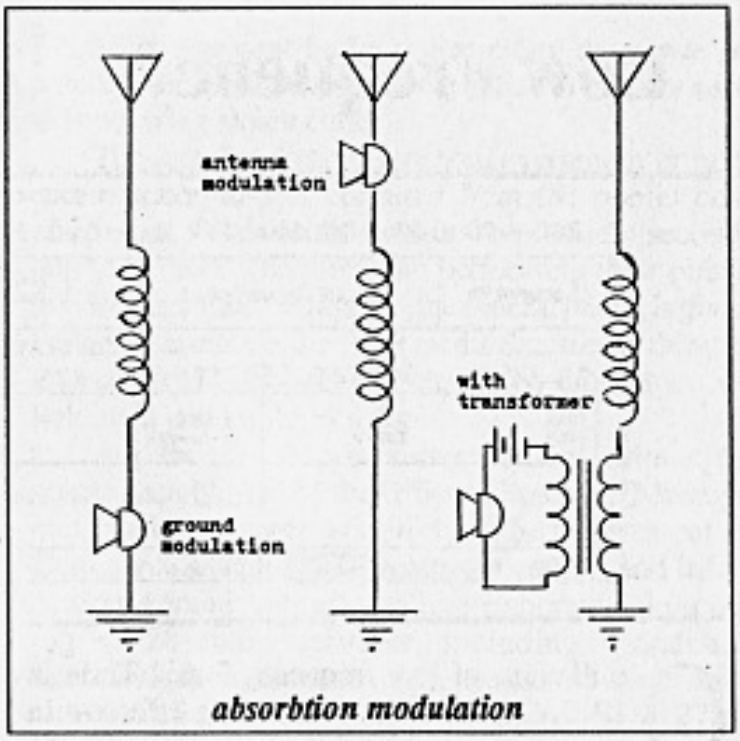


continuous-wave spark transmitter

were given. Is it necessarily low-fi? Does it cause unwanted FM effects, widening the band-width unacceptably? I have seen reference to the carbon microphone overheating in multi-kilowatt rigs. The cure was a water-cooled microphone. KQW in San Jose, California broadcast voice and music circa 1912 on an arc transmitter heard for about a thousand miles, and WLW in Chicago boomed on the AM band in the early '30's with a half-megawatt spark transmitter. Both used the antenna-absorption method.



magnetic shut-off



absorbtion modulation

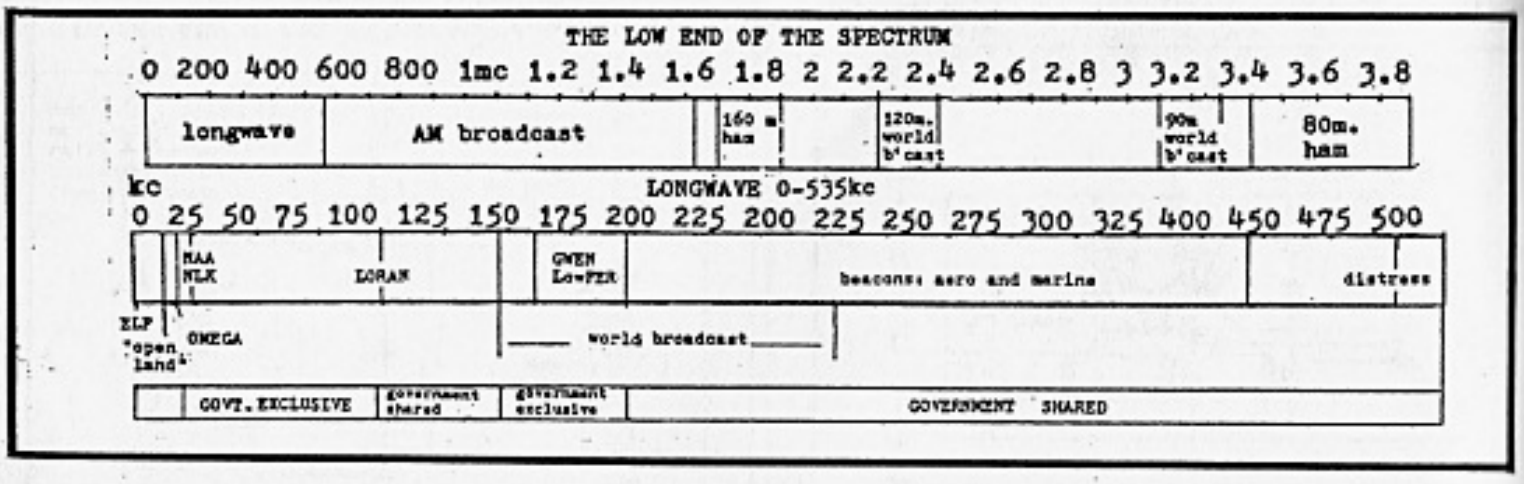
Tesla's available notes and patents tell us very little about his particular modulation schemes (his Colorado notes show an "arc controller"), but as the promoter of a world broadcasting system he seemed supremely confident that his magnifying transmitters could be modulated.

The passing of spark marked the end of Tesla-style high-voltage, sudden-pulse transmitting.

for more information

Tesla Coil by George Trinkaus. A how-to for the nonexpert. How Tesla did it. How you can from off-the-shelf parts. (**High Voltage Press**). **The Tesla Coil Designer** by Walt Noon is a computer program. (3283 Belvedere, Riverside, CA 92507). **Theory of Wireless Power** (book) and **Tesla's Longitudinal Electricity** (video) are among many Tesla titles from Borderland Sciences (P.O. Box 6250, Eureka, CA 95502). **Lindsay Publications** has many pertinent titles. (P.O. Box 12, Bradley, IL 60915).

2. Low Frequency



"Oscillations of low frequency," said Tesla in 1919, "are ever so much more effective in transmission, which is inconsistent with the prevailing idea." Radio at low frequencies (below the AM broadcast band) delivers more distance per watt. It is less vulnerable to atmospherics than shortwave. It does not suffer from the fade-in-fade-out syndrome that plagues shortwave. Low frequency radio is less affected by the sun. While much of shortwave is blotted out in daytime, low-frequency propagation is strongest at midday.

In early radio, the superiority of low-frequency was taken for granted. Shortwave was considered useless. But as radio attracted more practitioners, there inevitably developed a struggle for elbow room within the limited confines of the recognized radio spectrum.

who owns the ether?

Not surprisingly, the very first entity to claim ownership of the increasingly precious spectrum real estate was Government, in particular that of the U.S. through its navy. The U.S. Navy between 1900 and 1910 made several attempts to put radio under its sole control. The Navy, which during this period was already developing global marine communications and radio-navigation systems, was so assured of its right to rule the ether that it campaigned Congress for a monopoly of all of radio, both point-to-point and broadcast on sea and land worldwide.

The Navy also fought for the phase-out of spark and the development of a more refined radio. It set the specs for industry to develop the new continuous-wave technology.

Of course, the spectrum had not been waiting silently for government to step in and regulate it. The ether was already abuzz with activity, much of it conducted by the independent citizen-experimenters who ultimately became labelled (did they think it condescending?) as "amateurs."

The Navy introduced into Congress a series of bills that had the standard formula of providing for different classes of stations that would be registered and licensed, and then making it illegal for any outsider to interfere with these stations. No mention was made of the amateurs, whose transmitting stations (largely spark) were to number about 6000 by 1916. Thus, in these early legislative attempts, the hams were rendered de-facto outlaws. The Navy's campaign was ultimately joined by the Department of Commerce and by such commercial interests as Marconi's United Wireless. The hams, to defend themselves, organized into the still-active American Radio Relay League.

The legislation that finally passed (1912) did recognize the hams but banished them from any activity in the low frequencies. This was in the spirit of yes-you-can-go-swimming-but-don't-go-in-the-water, for low-frequency radio was all the radio there was. The short waves were then considered not only inferior but unworkable, the desert real estate of the spectrum.

The Government's final solution to the problem of a peoples' experimental radio was achieved, albeit briefly, in World War I when all amateur radio was

flatly outlawed for the duration. The Emergency Order, which came from the Dept. of Commerce and was signed by the Navy, banned not only transmitting but short- and long-wave listening as well. The order put radio under the full control of the Navy, which then tried to persuade Congress to make this situation permanent. Ultimately, federal control of radio was to pass out of the control of the Navy and into the Dept. of Commerce, until the Radio Act of 1934 created the FCC.

WWI also provided the opportunity for the government's destruction by dynamite of Tesla's magnifying transmitter tower, which still stood sturdily at Wardencliff, Long Island, a curiosity to passers-by. The excuse given was that the tower could be used by "spies," but the intention must have been to erase this monument to Tesla's alien radio and wireless power.

During WWII the government ordered another blackout of amateur radio.

The hams are still on the defensive. As I write the ARRL is dealing with a threat to yet another amateur territory way up in the spectrum at 222 megacycles, a band United Parcel Service and others are pressuring the FCC to reallocate to land-mobile uses.

The low frequencies, under the control of government, have been allocated to military and other bureaucratic functions, to navigation beacons, like Omega (10-14 kc) and LORAN (100 kc), and for weather stations, and time registers. Tesla had suggested low-frequency navigation systems. Some of the military transmitters are humungous, like the Navy's 3000 acre NAA command facility (24 kc) that runs 2 million watts and ELF down at 76 cycles, which uses antennas over 50 miles long.

citizens' radio

The government-military takeover of radio (nearly 100 percent of the low bands and much of the upper spectrum as well) has impacted on the amateurs, who have had to justify themselves as a quasi-government "service" in order to retain the privilege of radio. The amateurs' awkward posture is: "We are an emergency service, but, until an emergency comes up, we'll just be jawboning here to keep these bands open."

As early as 1925 the hams were building close functional relationships with the military. During the amateur blackout of WWII, many hams, as a way of staying active, enlisted in a military-run civil-defense program called the War Emergency Radio Service. Before government had a police radio, there was an amateur service that assisted the police in matters such as recovering stolen cars.

The fact that there is any nongovernment or noncommercial radio is obscured from the public consciousness. While hams sometimes get a few seconds on the tv news when they are performing their public service during an earthquake, the general public is given little awareness via the mass media that such a thing as a citizen's radio exists. On the tv the only character holding a radio mike is a cop.

A colorful wall-poster chart of the entire radio spectrum published by the Office of Spectrum Management (a bureaucracy within the U.S. Department of Commerce's National Telecommunications and Information Administration) provides elaborate color coding of 28 radio services, including broadcast, radionavigation, amateur, etc., but has no code for a citizens radio, and the 40-channel citizens band at 27 mc is ominously absent from the chart.

Regulation of the ether can never be absolute. Some governments, like Italy's, have had to abdicate some of their control over broadcasting to independents ("pirates"). Pirate radio and tv flourish where a state radio tries to dominate, and, by the same dynamic, where broadcasting is dominated by a handful of media corporations acting as one, piracy will predictably rise up. (Some people believe in keeping a gun in the house by way of providing for some impending political catastrophe. I'm not a gun person, but I do advocate keeping a transmitter handy. Does the First Amendment guarantee the right to bear transmitters?) The FCC once thought that it controlled CB, but when CB exploded with the advent of inexpensive transceivers made possible by the phase-lock loop frequency synthesizer, the government found it could not enlist the cooperation of all operators in a licensing procedure and threw up its hands. CB may be anarchy, but it still works, and the FCC can't do much about the kilowatt linears anyway.

black-box consumers

There is little encouragement for hams or anybody else to explore radio experimentally. The literature testifies to a time when way opened more easily for the curious and the experimenter. Published between 1900 and 1930 were at least twenty different monthlies for the electrical experimenter. These publications were full of projects, including transmitters and receivers, that one

could build in the basement workshop from parts easily available at independent dealers. Tesla, who published in the popular press, while avoiding the academic, was a star contributor to some of these magazines. The reader was assumed to be an experimenter, a builder, and capable of sustained thought, judging from the prose. Today he is assumed to be, above all, a consumer.

The typical ham through the 1930's built his own station, transmitter and receiver. By the mid-1940's he was still likely to build his own transmitter (though manufactured units were becoming available), but by then he had been persuaded that the manufactured receiver was superior to anything he himself could

DO NOT REMOVE COVER.
NO USER-SERVICABLE PARTS INSIDE.

build. Since the '60's the ham has bought both transmitter and receiver (even most of the kits popular in the '50's are gone), and today he is encouraged to buy, for $800 and up, both units boxed into one solid-state transceiver. Once an experimenter and builder, the ham of today is encouraged to become just another dependent consumer of black-box electronic components, which he himself often cannot even repair. In the case of broadcasting, the FCC prohibits a licensed operator of an AM, FM, or tv station building his own transmitter, and the FCC dictates design, hence cost. Today, among the few who build their own, is the pirate broadcaster, though he is also likely to convert an old ham rig. Many of the radio listeners of yesteryear built their own receiving sets for broadcast AM listening as well as shortwave, but by 1930 this became unfashionable due to the abundance of manufactured units.

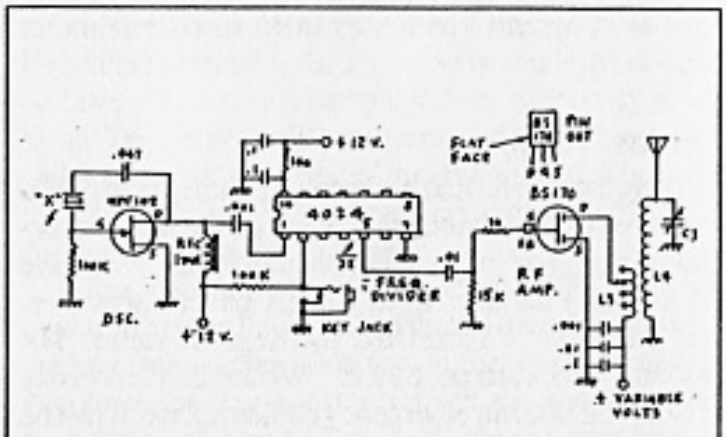
With today's integrated circuits, even the do-it-yourself discreet-component builder and experimenter becomes a consumer of tiny black boxes whose concealed workings he may only dimly understand.

Sealing up electronics in black boxes discourages the curious, while it promotes a priesthood, and so does the conventional electronics education and its textbooks. The innocent student, from the first day, is snowed under with mathematical formulae – information that could be useful someday if he were allowed to engineer a circuit, but it cannot tell him how electricity works. (Your author in his checkered past was an editor of a series of those "basic" electronics texts; his Tesla work may be an act of penance.) Tesla, a consummate mathematician, was skeptical of mathematical explanations. He called Relativity "a mass of deceptions wrapped in a beautiful mathematical cloak." Tesla had no good words for the electronics theory that grew out of quantum and Einsteinian physics. He is on record as saying that "there is no such thing as an electron."

low-frequency revival

While conventional histories congratulate the amateurs for turning shortwave into viable radio (the hams invented the shortwave technology the Navy and others would adopt), the allocation of hams to frequencies above 1500 kc meant their exile from superior turf. The banishment of hams from long-wave along with the romancing of the shortwaves has resulted in the almost complete lapse from public memory of low-frequency radio and what it means. This is particularly true in the U.S., for there is some long-wave broadcasting abroad, which, incidentally, can be received here to some extent on both coasts.

But in recent years there has been a revival of longwave. Low Frequency Experimental Radio people (LowFERs) transmit license-free in the 1750-meter band (160-190 kc) with government sanction under Part 15 of the Federal Communications Act, the same little-known part of the law that permits flea-power community broadcasting. The law limits LowFERs to just one watt and to a 50-foot antenna-ground system. Under



from The Low Frequency Scrapbook by Ken Cornell

low-frequency transmitter (160-190 kc)

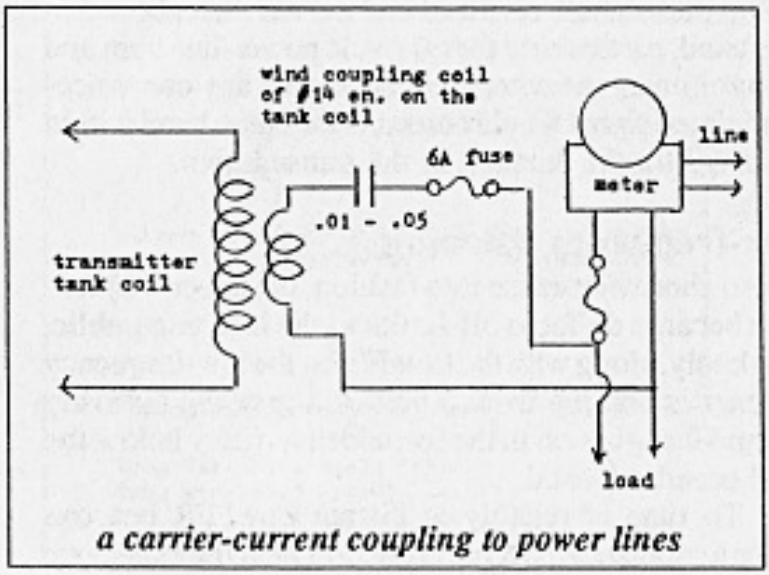
ideal conditions, a legal LowFER signal can be heard for up to 1000 miles, testimony to the power of longwave. But there are so many competing disturbances in these frequencies from broadcast harmonics, powerline harmonics, powerline-carried noises from motors and light dimmers and many other inadvertent transmitters, that reception is almost impossible in urban environments. Most LowFERs set up telegraphic beacons, listen for each other, and report reception in their networking newsletters, publications that are in the avant-garde of experimental radio. LowFERs are among the few who build their own. LowFERs remain true to the experimental spirit that marked early radio. They are willing, as one LowFER put it, to "reinvent the wheel." LowFER reception requires the experimenter to go mobile into the boondocks where it's electronically quiet, but even then signals may be overwhelmed by GWEN, a nuclear-doomsday Air Force system having about one hundred sites across the country. GWEN operates in the same band assigned to the one-watt LowFERs and its stations rehearse daily, emitting bursts of heavily encrypted radio teletype. (The same federal spectrum chart that forgets CB assigns a "government exclusive" code to all of LowFERland.)

Most LowFERs are resigned to working experimentally within the challenging constraints of the government-mandated one watt, but some are agitating for more practicable levels of power.

Closely allied to the LowFERs are the MedFERs, medium-wave experimenters who operate just above and below the AM band with a 100 milliwatt power limit, the same flea-power limit applied to community broadcasters. The upper MedFER territory has been opened to commercial broadcasters, but these experimenters will continue in the band until displaced. A few broadcasters are already operating in the band; their viability depends upon the manufacture of receivers with extended AM-band coverage.

carrier-current radio

When amateur radio was outlawed in WWII, the only activity open to hams, outside of enlisting in the Wartime Radio Service, was a low-frequency radio propagated over the power lines. Called carrier-current or wired wireless, this little known mode of radio is particularly effective at low frequencies. Line transformers tend to choke out high frequencies, but low frequencies



a carrier-current coupling to power lines

conduct through. The WWII hams worked voice and code down at 160 to 200 kc.

Power companies use such a low-frequency system today to transmit information between stations. Powerline carriers are another nuisance to low frequency listeners.

For the independent broadcaster, carrier current is an option. Within flea-power watt restraints, it's even legal under Part 15. Independent and community broadcasters use carrier current for transmitting both AM and FM. Receivers need not be coupled to the lines; even car radios can get the signal from the overhead wires. Though the AM band is five times higher than the frequency a power company or a WWII ham would use, AM probably does some penetrating of transformers. I recall that my college AM carrier-current station did a good job of getting around the entire campus as well as much of the adjoining small town.

open land

Did you know that in the basement of the very crowded, highly controlled radio spectrum, down at 0 - 9000 cycles, there is no government regulation? Thus, this unallocated very low frequency band is open to unlicensed experimenters at any power level. Conceivably, one could set up point-to-point communications using just everyday audio amplifiers. An underwater diver communication system uses 10-watt audio amplifiers. Output is connected to widely spaced submerged electrodes as antennas. The idea might be tempting to audiophiles who would be radiophiles. A problem would

be the noises, both civilized and natural, that abound in this band, particularly the 60-cycle power-line hum and its harmonics. Another problem is that any one voice-modulated signal would consume the entire band within its range for the duration of the transmission.

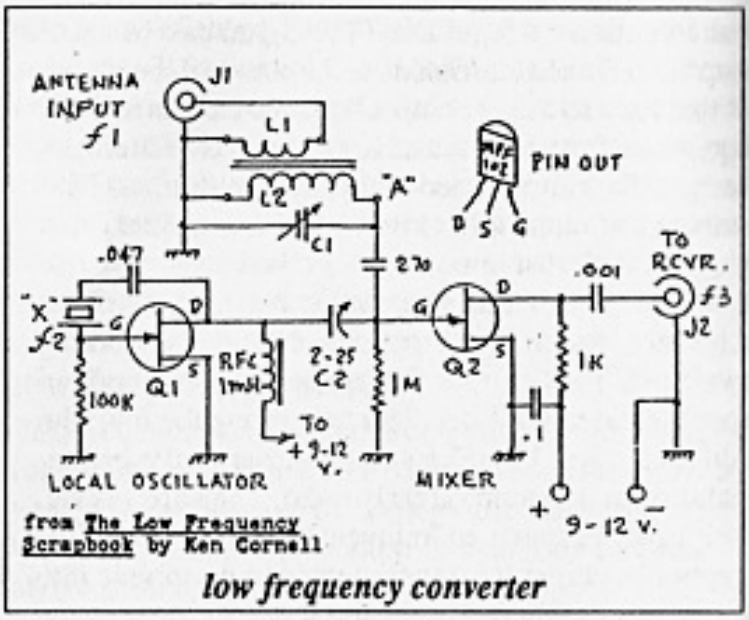
low-frequency listening

When shortwave came into fashion, the lower frequencies became de-facto off-limits to the listening public. But lately, along with the LowFERs, the low-frequency listener is coming back. There is a growing curiosity about what goes on in the forbidden territory below the AM broadcast band.

To tune in reliably to distant LowFER beacons takes a sophisticated receiver with crystal filters and one kilocycle dial resolution, but I can testify to the enjoyment provided by seeking stronger beacons on my simple, one-transistor, uncalibrated home-built regenerative unit shown later herein. If you own a shortwave receiver, you may want to try a solid-state converter like the one shown above. Beacons are radio-telegraphic lighthouses that repeat slow alphabetic identifiers (good code practice). Called NDB's in LowFER jargon, marine non-directional beacons run only about 25 watts, while the FAA's aeronautic beacons can go to a kilowatt. There are directories that can tell you the location of beacons heard, if you want to take it that far. Also you may hear maritime ship-to-shore telegraph as well as big military transmitters, along with a lot of other strange signals you just have to wonder about. Receiving the megawatt foreign low-frequency broadcast stations is a possibility if you live on either U.S. coast. Any low-frequency listening is subject to suppression by civilized electrical noise and benefits from a nonurban environment. It is in urban listening that the expensive well-filtered receiver pays off.

natural radio

With a very low-frequency receiver (below 30 kc), you can hear the sounds of natural radio: spherics, hisses, pops, chirps, tweaks, whistlers, as well as something called the dawn chorus. Tesla listened to the sounds of VLF radio and conjectured that among the disturbances were signals from Mars. ("A clear suggestion of number and order," he noted; "impossible to think accidental...a purpose was behind these signals.") Experimenters today who tune in to nature's radio use receivers of various degrees of sophistication, but, according to Michael Mideke in his *Sounds of Natural Radio*, "given a large enough antenna, even amplification can be dispensed with; signals can be heard using nothing more than headphones connected between antenna and ground."

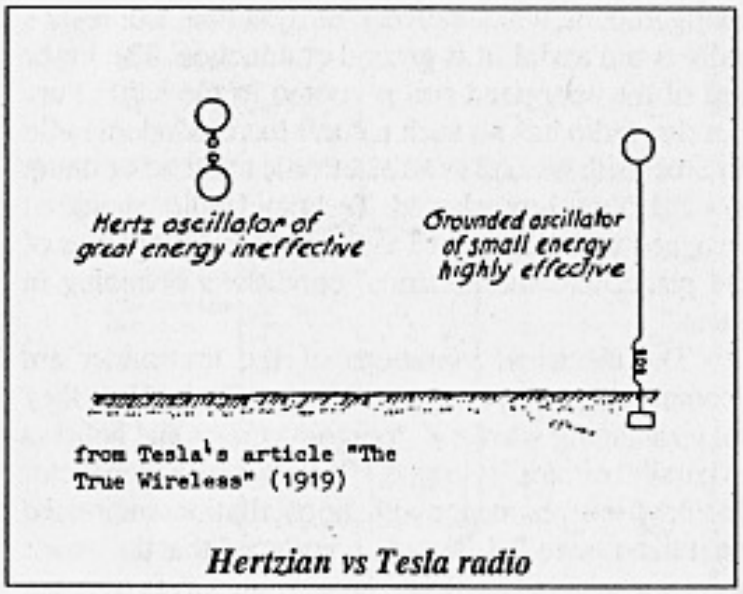


low frequency converter

for more information

200 Meters and Down, The Story of Amateur radio by Clinton DeSoto, 1936, (ARRL, 225 Main St. Newington, CT 06111). **U.S. Frequency Allocations, The Spectrum** is a full-color wall poster chart (U.S. Govt. Printing Office, Washington D.C. 20422). **High Power Wireless** (1910) and **The 1934 Official Shortwave Manual**, Hugo Gernsbach, ed. (all three from Lindsay). **The Lowdown** is the LowFER and MedFER newsletter, Bill Oliver, ed. (Longwave Club of America, 45 Wildflower Rd., Levitown, PA 19057). **Carrier Current Techniques** by Ernest Wilson (Pan Com, P.O. Box 130, Paradise, CA 95969). **Low and Medium Frequency Scrapbook** by Ken Cornell, the bible of LF tech (225 Baltimore Ave., Point Pleasant Beach, NJ 08742). **Tesla: Contact with Mars** (Rex Research, P.O. Box 19250, Jean NV 89019).

3. Conduction Through the Ground


Hertz oscillator of great energy ineffective
Grounded oscillator of small energy highly effective
from Tesla's article "The True Wireless" (1919)

Hertzian vs Tesla radio

The propagation of radio signals and wireless power Tesla saw as a matter of conduction. Tesla's radio-conductive path was not a circuit in the conventional sense but was modelled on the single-wire-without-return principle that he demonstrated in his high-frequency, high-voltage lighting system. Electric researcher Eric Dollard calls this one-way conductive effect "longitudinal electricity."

Tesla's radio-conduction can happen either through the earth or through the sky. Tesla said, "The earth behaves simply as an ordinary conductor." He said the earth was superior conductor; but, pertinent to sky transmission, Tesla is on record in a patent as saying that "transmission through elevated strata encounters possibly less resistance than copper wire."

Conventional theory never hints at radio propagation being anything like conduction but represents it as some kind of radiation. This is more than a textbook convention; a whole science of antenna design is based on this assumption, which Tesla dismissed.

an etheric medium

What is radio, anyway? The texts, like my *Radio Amateur's Handbook*, speak of radio as "radiation." But, at the same time, it is a "wave." Then again, in the same paragraph of the *Handbook*, which is just echoing respectable physics, we are told that it is "traveling electrostatic and electromagnetic fields." Whatever it is, some sort of almost material emanation is presumed to be issuing from the antenna into a void.

Tesla, however, saw radio as a "disturbance of the medium," or a "commotion in the medium." He writes of "transmitting an electrical movement to the environing medium." What is this medium?

In Tesla's time it was an article of faith that there existed a unified field that permeated all being, all matter, including solids, liquids, and even what we call space or vacuum. This pervasive "ether," as it was called, is the medium of radio. The transmitter sets up a disturbance that produces, says Tesla, "alternate compressions and rarefactions in the medium." This suggests some kind of elastic continuum that conducts standing waves.

Coming from this view, all electric phenomena — charge, polarity, oscillation — involve some kind of strain or vibratory disturbance of the equilibrium of the ether.

The etheric perception of radio came naturally to early experimenters. Loomis writes of his aerial telegraphy as "causing electrical vibrations or waves to pass around the world, as upon the surface of some quiet lake one wave circle follows another from the point of disturbance to the farthest shores."

In Tesla's radio, effective transmitting is achieved by setting this elastic medium vibrating with a sudden high-voltage whack, like that created by the discharge of a capacitor.

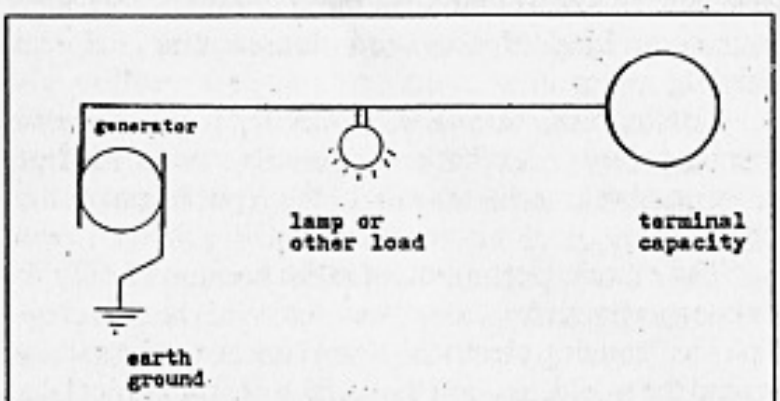
grounded radio

Hertzian radio has us all conditioned to thinking in terms of aerial radio: "the air waves," "on the air." Extreme importance is placed on the antenna and its

configurations, which can become byzantine. But Tesla's radio is not aerial. It is ground-conduction. The lower end of the energized coil is rooted in the earth. Pure Herzian radio has no such natural load. Modern radio regards earth ground as an electronic toxic waste dump to which noise is conducted. Tesla said radio "should be designed with due regard to the physical properties of the planet and the electrical conditions obtaining in same."

The electrical vibrations of the transmitter are "communicated to the ground," says Tesla. Here they set up standing waves — "outgoing crests and hollows in parallel circles." He said, "The terrestrial conductor is thrown into resonance with the oscillations impressed on it like a wire." Tesla was convinced that the waves were not "electromagnetic" since such waves were not likely to travel through the earth. Tesla's ground wave, unlike Hertz' aerial, does not travel uniformly at the speed of light and can even reach a velocity that is infinite.

Oscillating the entire electrostatic Earth was among Tesla's many ambitions, and he observed that "the planet behaves like a perfectly smooth and polished conductor of inappreciable resistance." He went on to characterize the globe as having "capacity and self-induction uniformly distributed along the axis of sym-

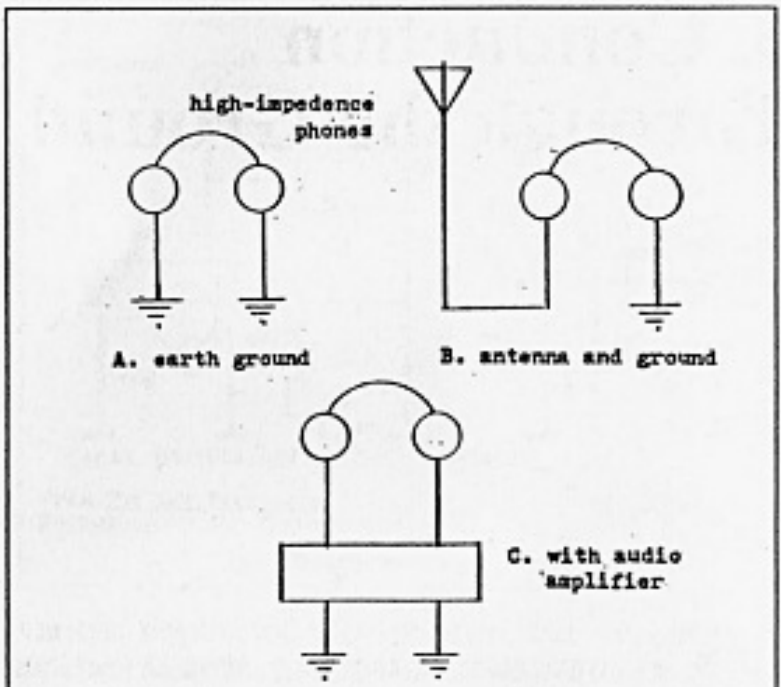


single wire without return

metry of wave propagation." In the same text (a patent applied for in 1902), Tesla added that these standing waves propagate "without attenuation." That is, he is saying they do not diminish in intensity over distance.

no ionosphere

Tesla believed Hertzian aerial radio was a waste of energy. Tesla suggests that there is some radiation



audio-frequency grounded radio

component in a radio transmission but that it is a weak and incidental output. He thought the theory that high-frequency signals travelled long distances by bouncing off some high-altitude, radio-reflective layer called the ionosphere was "an utter impossibility." Tesla was not alone in disputing the existence of the Heavyside Layer, as the ionosphere was called then; it was quite controversial for a time before it was frozen into official science. Tesla said that Hertz wave theory "by its fascinating hold upon the imagination, has stifled creative effort in the wireless art and retarded it for 25 years."

audio radio

In World War I, when field telephones were used that stretched long wires over the surface of the ground, it was discovered that one could eavesdrop on opposing forces' conversations just by connecting headphones to ground rods. This discovered, effective monitoring systems were developed by both sides that consisted of two widely separated ground rods connected to a sensitive audio amplifier. Here was a Tesla-like radio: low-frequency conduction through the earth. There is no reason you cannot use this principle for an audio-frequency radio in the unregulated open land below 10 kc. When you consider that radio can happen in the

audio band, you have to wonder about the term "radio frequency" (rf), as in "rf energy," etc., which seems to imply that radio is a function of frequency.

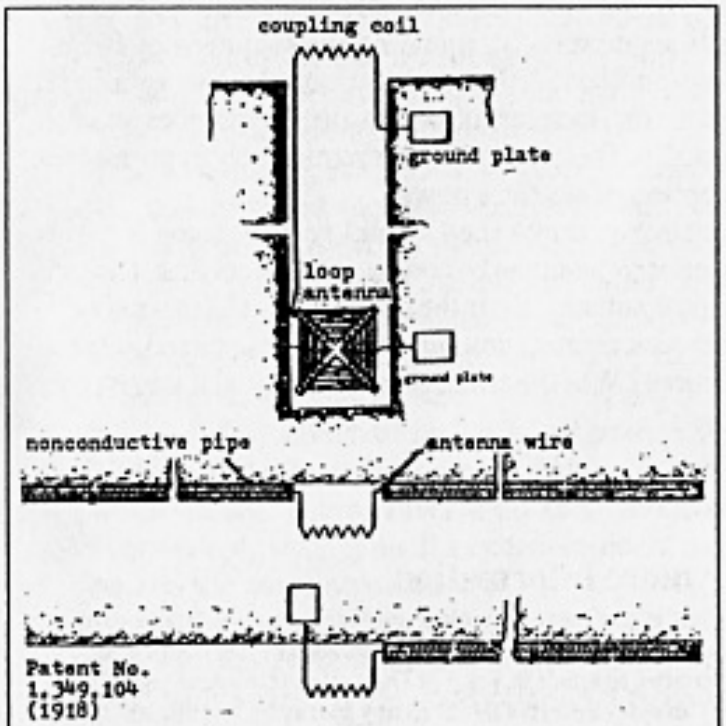
Disturbances caused by the various electrical happenings in nature, such as lightning-created static crashes, an occasional whistler, and other strange sounds can also be heard using the above system, and it so happens that the WWI eavesdropping apparatus was sometimes totally jammed by such natural activity.

underground radio

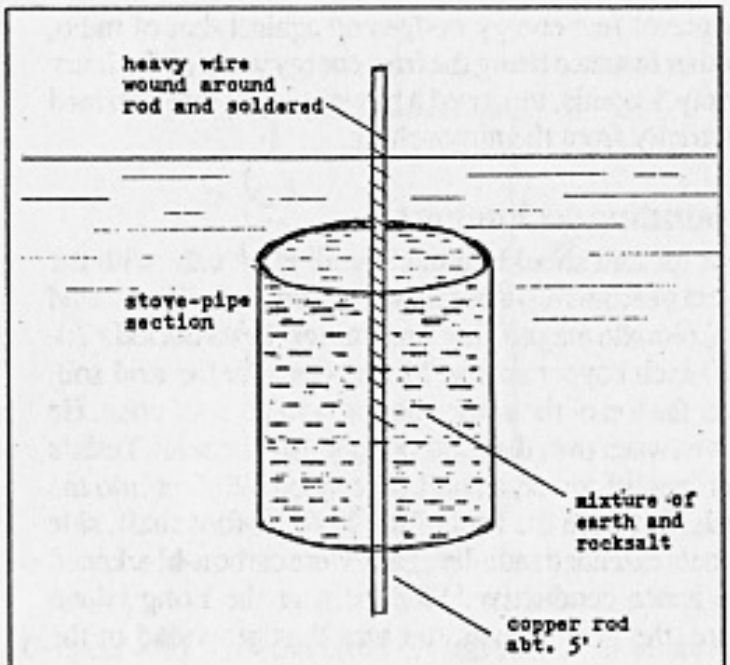
A follower of Tesla, James Harris Rogers, patented (1920) a radio system in which both sending and receiving antennas were sunk completely underground or underwater. Rogers had his own doubts about Hertzian radio. He wondered, "If 50 units of power are passed into the aerial, then what becomes of the equal amount of energy which passes into the ground?"

Roger's was working at low frequencies, but nothing in his patents limits his grounded radio to the low band. The Rogers underground achieved superior signal strength. According to accounts, reception was free from atmospheric static, and there was no diminishing of the signal in daytime.

The Navy used the Rogers system secretly in WWI and announced it to the public in 1919. An editorial by



Rogers underground radio



stove-pipe ground

the famous editor Hugo Gernsbach in the March 1919 issue of the *Electrical Experimenter* predicted that "the greatest pride of the radio amateur, the aerial on top of his house...is doomed... As for commercial stations their towers are doomed shortly for the scrap heap." Tesla himself had said, "The great amount of energy which can be conveyed to a [receiving] circuit by conduction through the ground, makes it appear possible that the necessity of elevating terminals...may be dispensed with." Gernsbach, who published much on Tesla in his time, said, "All our pet theories on wireless are thrown into chaos," and he predicted "a war to the knife between our wave-propagation theorists and the new school of ground-impulse savants."

This noted, the Rogers underground vanished from the media, and Rogers' career took a downturn reminiscent of Tesla's.

Stubblefield

In 1902 Nathan Stubblefield demonstrated a grounded wireless-telephone system of his own invention. Sticking iron rods into the ground at the Virginia shore of the Potomac River, Stubblefield communicated with a steamship half a mile away. Stubblefield's grounded radio was powered by the high-frequency output of his Stubblefield battery (patent No. 600,457), a type of space-energy receiver, which shows how the occult

science of free energy nudges up against that of radio, another instance being the free-energy work of T. Henry Moray. Loomis, too, used a power supply that obtained electricity from the atmosphere.

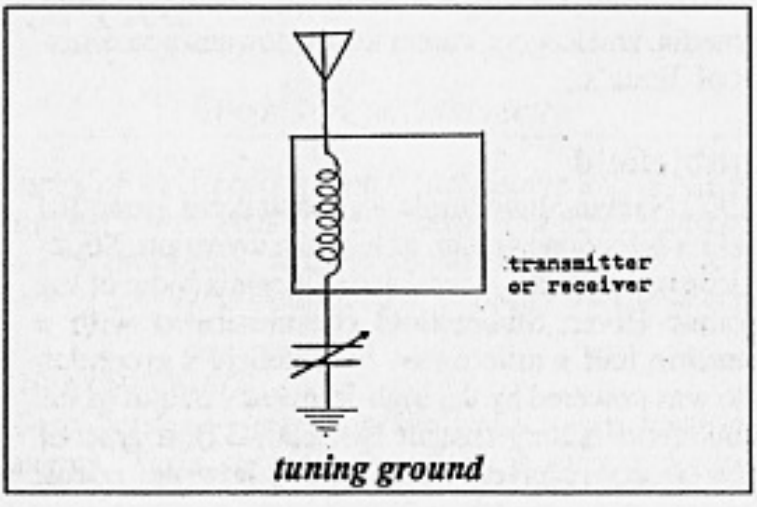
grounding technology

"The ground should be made with great care with the object of reducing its resistance," said Tesla. To ground his Colorado magnifying transmitter, Tesla buried a 20-x-20-inch copper screen 12 feet down in the arid soil. Over the top of the screen he spread a layer of coke. He flowed water over the spot continuously. Beneath Tesla's Wardencliff tower, a shaft descended 120 feet into the earth. Out from the foot of the 12-x-12-foot shaft, side tunnels extended radially. They were carbon-blackened and hence conductive. Situated near the Long Island shore, the giant transmitter was thus grounded to the oceans.

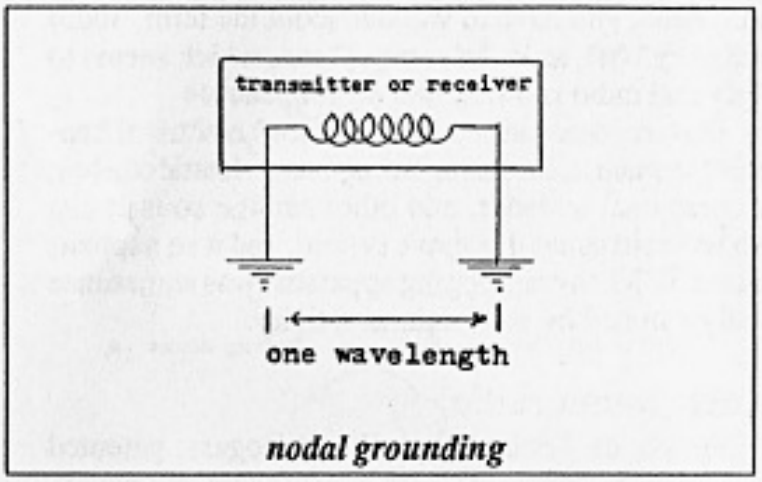
Such solid grounding has become another lost radio art. Until the 1950's even commercial broadcast receivers had a ground terminal on the chassis that one was encouraged to connect to a cold-water pipe or other ground; some houses had a radio ground wired into a wall socket.

A 1930's shortwave magazine recommended a stovepipe ground: a buried stove-pipe section filled with a mixture of soil and rock salt, which attracts moisture. Charcoal can be mixed in, as Tesla used coke. Down the center runs five feet of solid copper rod or galvanized pipe around which is wrapped the heavy lead-in wire.

Any conductor used to connect radio and ground should be as short as possible and with the heaviest conductor, such that an excessively long run of, say, twenty feet is best done with a wire gauge of zero or bigger or maybe with copper tubing or galvanized pipe.



tuning ground



nodal grounding

Clamping securely on to cold-water plumbing near to its ground-entry point is good grounding but this can be supplemented by other grounds, like earth rods or existing fence posts. Any body of water makes a good ground. Connect to a large submerged metal object. Any radio, transmitter or receiver, becomes hyperactive near or connected to a body of water.

Older schematics show a variable capacitor between output coil and ground, comparable to an antenna tuner. I've adopted this practice of tuning ground with good results, including noise control in receiving.

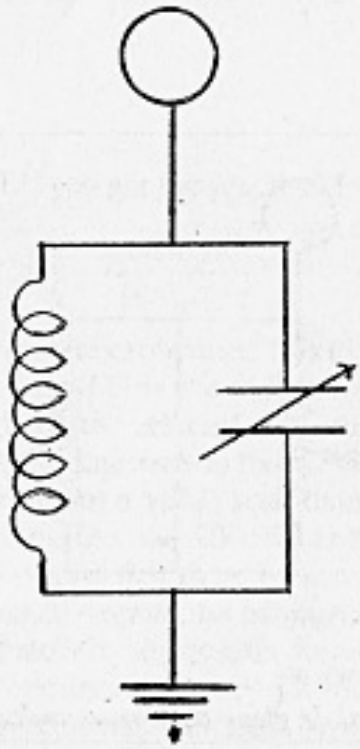
Tesla's radio assumes standing earth waves, and Tesla recommends grounding the two ends of the receiving coil one-half wavelength apart at a wave's nodal points, the location of which one determines experimentally. This arrangement is particularly important for reception of wireless power.

Having established a solid ground, some interesting experiments can be conducted in receiving. Disconnect the antenna. Does the signal vanish? What happens when you connect ground to a receiver's sacred antenna terminal? Will the Hertz police arrest you if you try any of this?

for more information

Underwater Communication, includes some of Rogers patents (Rex Research). **Subsurface Antennas and the Amateur** by Richard Silberstein, an article in Vol. 1 of *The Antenna Compendium* (ARRL). **The Complex Secret of Dr. T. Henry Moray** by Jorge Resines, radio and TV circuits from 1928 applied to Moray's free-energy discoveries (Borderland).

4. Resonance



The idea of properly harmonized coils and capacitors vibrating with sympathetic reinforcement and thereby magnifying effects by tremendous ratios is at the heart of Tesla's technology.

Tesla's basic radio tuning "tank" circuit (coil plus capacitor between aerial and ground) is, all by itself, a powerful resonant signal amplifier and a beautifully simple one. Tesla suggests the power of a coil to vorticize energy. But as radio developed over the years, the tank coils in both transmitters and receivers shrank in size, and the result was a loss in gain that was compensated for by the addition of stage after stage of complex amplification circuitry using vacuum tubes.

Tesla watched this development with bewilderment. For transmitting, the resonantly tuned circuits of the tesla coil provided the high electromotive force Tesla thought necessary for long-distance radio-conduction. For receiving, the big loading and tuning coils "magnified effects," as Tesla liked to put it. So why depend on complex, multi-stage circuitry to amplify? It didn't make sense to Tesla. He said, "My plans involved the use of a highly effective and efficient transmitter conveying, at whatever distance, a relatively large amount of energy. The receiver itself is a device of elementary simplicity... In such a system resonant amplification is the only one necessary."

Taking the tank circuit another step out, Tesla conceived of a receiving coil made of glass tubing that was filled with a rarified gas, thus offering almost no impedance to the signal. This superconductivity would, he reasoned, result in tremendous gain.

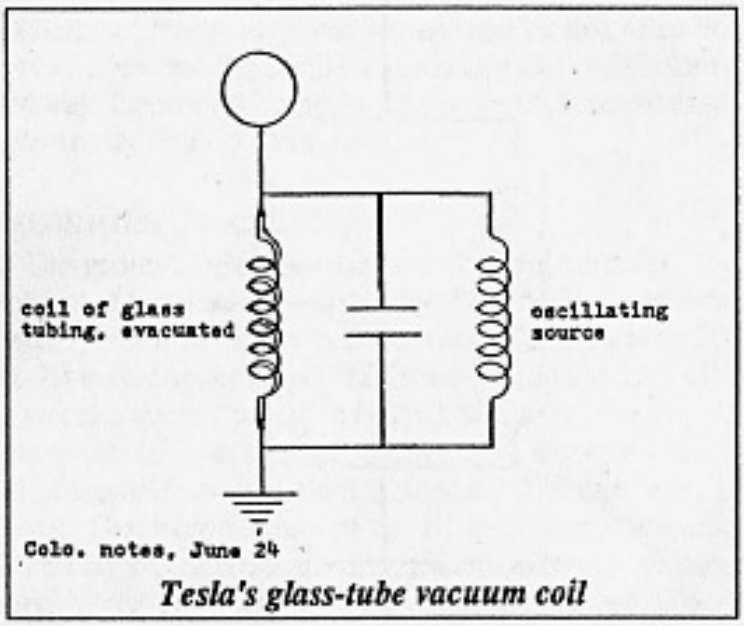
I've heard tell of a radio experimenter in Portland, Oregon who built the basic crystal set on an obscene scale with a broadcast AM-band tank coil four feet in diameter and and six feet long, wound of copper tubing. Tuned with a big old commercial variable capacitor, the single-stage set, void of amplifier stages, drove an eight-inch loudspeaker with room-filling volume.

earth resonance

Tesla calculated the frequencies and pulsings of his transmitters with an eye to resonating the earth. Earth resonance is fundamental to Tesla's grounded radio and wireless power. Tesla suggested that the electrostatic earth resonated at a particular frequency, and seems to be suggesting that the closer the vibration is to that frequency the greater the magnification of effects.

What is this magical earth-resonant frequency? In his Colorado notes, Tesla says the wavelength is 5200 feet or 1737.7 meters, which works out to about 173 kc. Tesla's Colorado transmitter ranged from 60 kc to 190 kc; 170 kc was a typical operating frequency, according to the *Notes*.

In a 1920 patent, however, Tesla specifies that the frequency should be "smaller than 20 kc, though shorter waves may be practicable." The lowest he would allow would be 6 cycles per second, to which he adds that "paradoxical as it may seem, the effect will be greatest in a region diametrically opposite the transmitter." In another fundamental radio patent, Tesla says he has learned to set up standing waves in the earth. "I found," he says, "their length to vary approximately from 25 to 70 kilometers." This works out to 428 cycles to 12



Tesla's glass-tube vacuum coil

kilocycles. If earth resonance happened for Tesla below 60 kc, then he did not achieve it on his Colorado transmitter unless it was by harmonics.

In the 1920 patent Tesla said, "The most essential requirement is...that, irrespective of frequency, the wave or wave-train should continue for a certain interval of time, which I have estimated to be not less than 1/2 or probably .08484 of a second — the time taken in passing to and returning from the opposite pole at a mean velocity of about 471,240 kilometers per second."

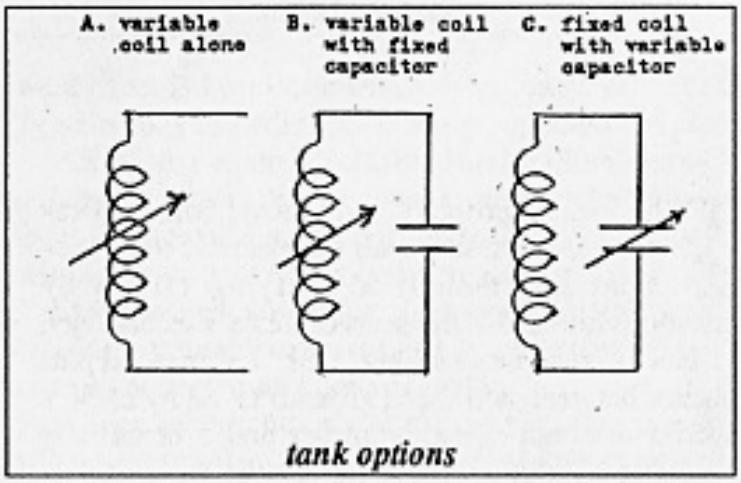
Recent thinking on the earth-resonance mystery hypothecates an earth-ionosphere waveguide, a Hertzian notion that would set Tesla spinning in his grave. Tesla spoke only of resonating the earth itself. The Schuman Cavity, as this waveguide is called after its theorist, is said to resonate at exactly 7.83 cycles.

the resonant tank

Of his Colorado transmitter, Tesla wrote, "The vibrating system is formed by a continuously variable and exactly determinable inductance and a capacity standard, or by an inductance standard and a continuously adjustable condenser, or by a system in which both these elements are continuously adjustable."

Modern radio technology has settled on the second of these options for tuning — fixed coil and variable capacitor. This is the arrangement since the 1930's for both transmitters and receivers. But early radio shows a mix of options to accomplish tuning. Sometimes there is no capacitor, and tuning is accomplished with a variable inductance alone. Variable coils include the tapped coil, the slider, and the variometer in which one coil rotates within another. The tradition of the tapped and slider coils is preserved among builders of the crystal set. Almost forgotten is the capacity slider, a section of tubing which encircles the coil except for a narrow slit. There is a revival among LowFERs of the elegant variometer.

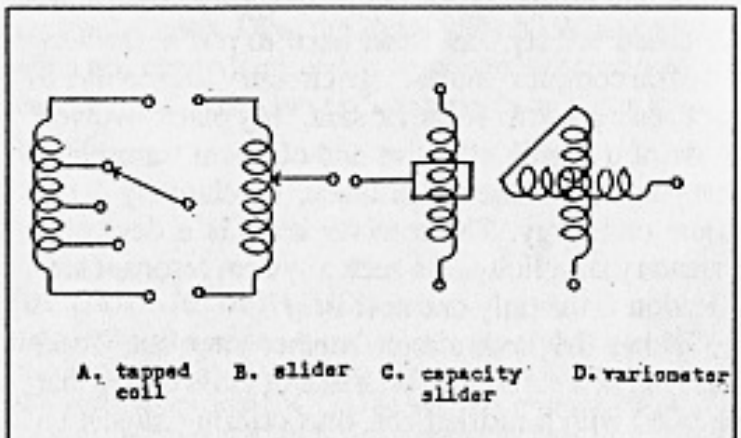
Variable capacitors include the familiar rotary plate (also called "air variable" because the dielectric is air), the simply constructed "book" type, (p. 22) and the tubular high-voltage type for transmitting. Old circuits



tank options

show variable capacitors consisting simply of a cluster of fixed capacitors and a rotary switch. Tesla's variable capacitor consisted of two opposing conductive disks whose distance apart was adjustable (p. 22). Transmitters sometimes use little neutralizing variables of this design, but I've seen it nowhere else. The book type was manufactured by Crosley in the 1920's. The tubular shows up in the transmitter literature circa 1910.

Even the popular rotary-plate type of variable ca-



types of variable coil

where L is the coil's inductance, N is the number of turns of wire, and A is the length of the coil winding, B the diameter, both in inches.

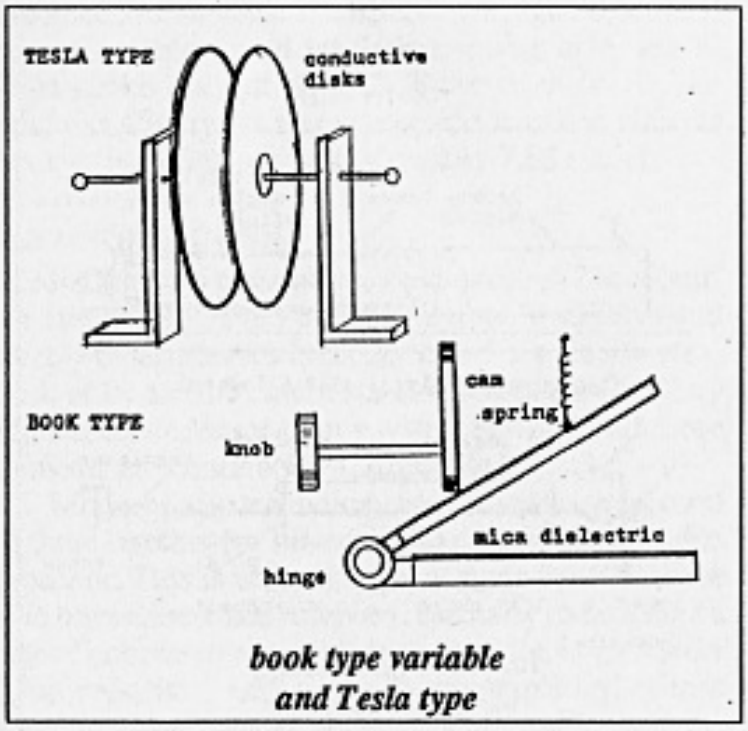
Divide the oscillation constant for the frequency you want by the capacitance in microfarads and you'll get the inductance in microhenries that you'll design the coil for. By transposing the coil formula, you can yield the number of turns. By plugging in lengths and diameters, the physical characteristics of a coil with the desired inductance will begin to emerge.

$$N = \sqrt{\frac{L(9A + 10B)}{A}}$$

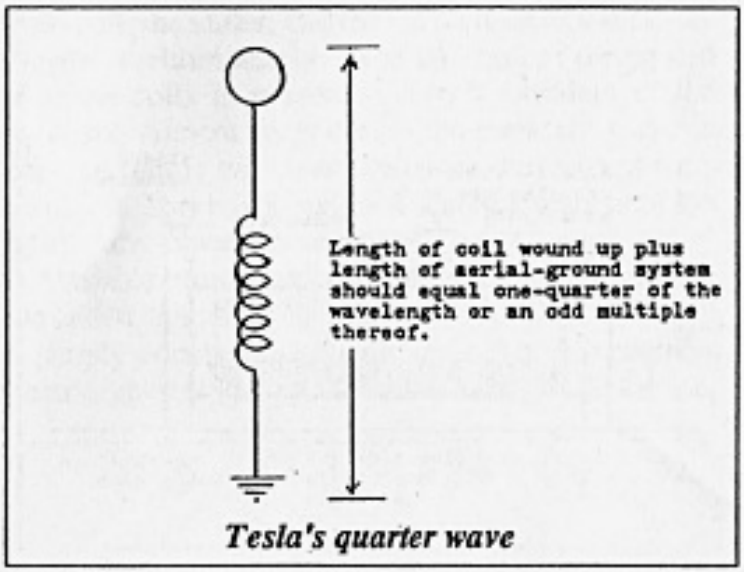
quarter-wave principle

Tesla advised a simple method of calculating the length of a tuning coil. Just divide the wavelength by four to get the length of the coil wound up. This length includes the length of the entire aerial-ground circuit. Odd multiples of the quarter wave, including, I assume, odd fractions, will also resonate at the frequency.

Tesla stated the rule: "In order to attain the best results it is essential that the length of each wire or circuit, from ground connection to the top, should be equal to one-quarter of the wavelength of the electrical vibration in the wire, or else equal to that length multiplied by an odd number."



book type variable and Tesla type


Length of coil wound up plus length of aerial-ground system should equal one-quarter of the wavelength or an odd multiple thereof.

Tesla's quarter wave

Tesla called his quarter-wave principle "the secret of tuning." He said that "without the observation of this rule it is impossible to prevent the interference and insure the privacy of messages."

Tesla's quarter-wave formula is still honored in calculating the length of antenna elements and is still useful in calculating an antenna-loading coil and for tuning circuits that have a coil alone without a capacitor.

building capacitors

If you are building a variable (or any other) capacitor from scratch this formula is useful. It also helps you calculate the value of unmarked variables that you find in surplus electronics stores:

$$C = .224K\,A/d\,(n - 1)$$

C is the capacity in picofarads (pf); A is the area of one plate in square inches; d is the distance between the plates in inches; n is the number of plates. K is the dielectric constant, an index of the insulative (dielectric) power of the material, air being the standard with a K of 1. You can more than double the K of a variable if you are clever enough to find a way to submerge the device in mineral oil, which has a K of 2.2 and you can more than quadruple the K in castor oil (4.7). Oil also ups the voltage-handing ability by a factor of ten or more.

Tesla built a salt-water capacitor for his Colorado magnifying transmitter. It consisted of salt-water in large mineral-water bottles immersed in a tank of salt-water. The "plates" are the salt-water, inside the bottles

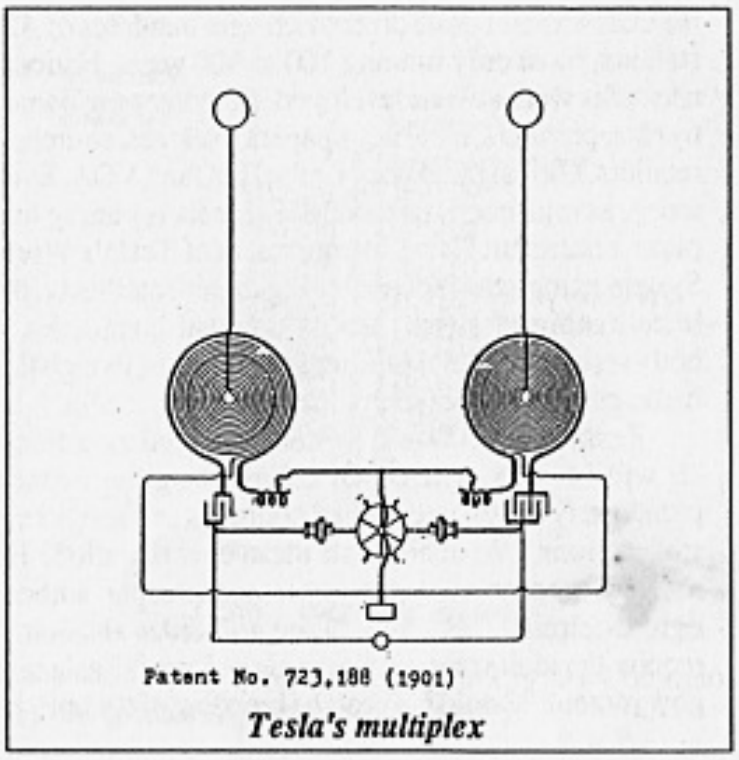
and outside. The dielectric is the bottle-glass. Tesla called the bottles "jars" (probably in the tradition of the Leyden jar) and measured capacity by how many jars he connected into the circuit. You can build an adjustable salt-water capacitor out of beer bottles (See *Tesla Coil.*)

World System

When the magnifying transmitter tower at Wardencliff was still under construction (1902), Tesla published a brochure advertising the project as a prototype for a global radio communications corporation. Called the World System in the brochure, it would serve as a multi-frequency wireless traffic center for all existing telephone, telegraph, and stock-ticker services around the planet. Built on Tesla's earth-resonant radio principles, the System would also carry a universal time register, navigation beacons, and even facsimile transmissions. It would also be a global system of broadcasting. Tesla was among the first to suggest broadcasting of news and entertainment to the public; only point-to-point signalling had been experimented with up to then.

Tesla's tower was never completed beyond the rugged framing, and the World System fantasy collapsed when Tesla's backing, from J. P. Morgan, was pulled suddenly from under him. This crushing event signalled the end of Tesla's official career.

Wardencliff tower



Tesla's multiplex

The system Tesla describes represents a huge jump forward from any radio technology of Tesla's documented in his Colorado notes, his patents, or anywhere else. The brochure suggest the achievement of precisely tunable, high-Q, limitlessly powered transmitting of multiple channels from a single point, transmitting that could be voice-modulated as well.

Little technical detail is given, but the promotional literature suggests that Tesla may have been planning to rely heavily on multiplex techniques to cut through noise. "My individualized system with transmitters emitting a wave complex and receivers comprising separate tuned elements cooperatively associated." He called the technique a "combination lock" and boasted that any degree of safety against statics or other kinds of disturbance can be obtained." The receiver is so designed that it responds "only through the joint action of the tuned elements."

Was Tesla a fascist?

You have to wonder since his World System would have taken radio right off the bat into global centralization, a fantasy of control beyond the dreams even of the U.S. Navy. As it turned out, a quarter century after Tesla proposed his System, broadcast radio, particularly within

the U.S. was still quite diversified with hundreds of AM stations, most only running 100 to 500 watts. National networks were still undeveloped. Stations were owned by entrepreneurs, local newspapers, colleges, churches, retailers. Global radio became the BBC and VOA. Even today, as multinational monopoly media is putting into place a decadent Hertzian equivalent of Tesla's World System using satellites, including direct-satellite tv, the broadcasting of signals across national boundaries is hotly resisted at diplomatic and other levels, though this battle gets no coverage in the mainstream media.

Tesla saw his World System as a civilizing force: "It will be very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions." What did Tesla mean by civilization? He said, "No community can exist and prosper without rigid discipline." He said, "Law and order absolutely require the maintenance of organized force." Tesla said government "should prevent the breeding of the unfit by sterilization and the deliberate guidance of the mating instinct."

Tesla is admired for his technological purism, his insistence that a machine possibility be carried to its logical conclusion. Society, too, was a machine, and it needed perfecting. The World System fitted into Tesla's ideals of social order. His logical conclusion for organizing radio was a system that was centralized, omnipotent, and global.

for more information

Henley's 222 Radio Circuit Designs, 1922 vacuum-tube technology, fascinating (Lindsay). **Tesla's Work with AC and Wireless**, edited by Tesla Researcher Leland Anderson (Twenty First Century Books).

From High Voltage Press

TESLA, The True Wireless edited by George Trinkaus **$7.75**

In Nikola Tesla's own words and in 21 illustrations, this is the inventor's final published statement on how radio, at the radical, really works. What is the true wireless? Tesla says the orthodox Hertzian radio we've been taught is a "fiction." He insists that the amount of energy that can be transmitted is "billions of times greater" than conventional radio would allow. Can we transmit electric power to our homes and workplaces without wires? Can the unsightly and fragile grid come down? Tesla claims his radio can deliver wireless power. This article of 1919 has been completely reset and redesigned for clarity. Includes an introduction by Trinkaus, explanatory notes, and information sources.

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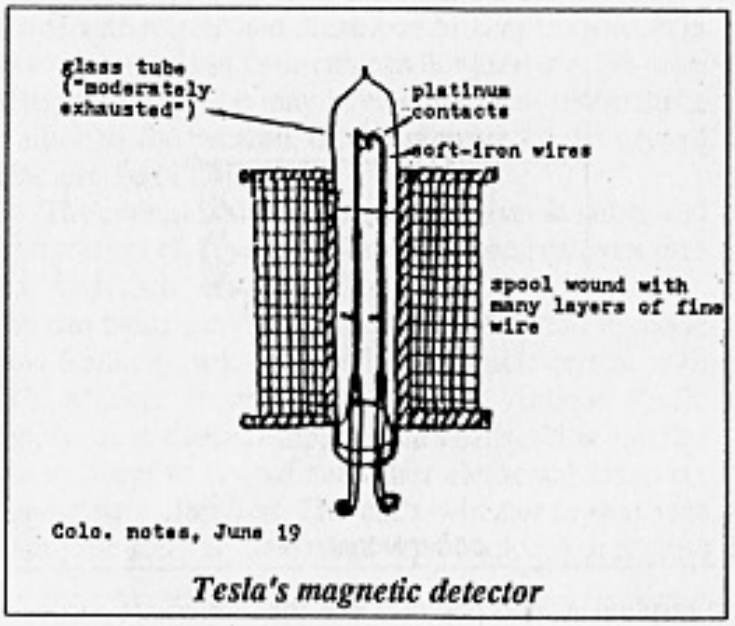
5. Sensitive Device


glass tube ("moderately exhausted")
platinum contacts
soft-iron wires
spool wound with many layers of fine wire
Colo. notes, June 19

Tesla's magnetic detector

Tesla gave a lot of attention to the development of the ideal apparatus for detecting disturbances in the medium. Tesla let his imagination run free in his quest for the optimal "sensitive device," as he called it.

the coherer

Tesla's detector research was paralleled by many others at the time. The popular detector among radio experimenters was the coherer. This is simply a short glass tube partly filled with small metal chips or filings. Strained to near-conduction by battery voltage, this early semiconductor mysteriously switches on when an oscillating disturbance is present. A tap is needed to reset the coherer back to nonconduction. Breaking the battery circuit also works. Tesla improved the coherer by setting it into constant rotation at about 16 RPM so it would automatically reset. Changing the rate of rotation controls sensitivity. In a patent he also mentions a vibrating coherer. Constant motion suspends the coherer's chips in space, making them more susceptible to disturbances.

The coherer's internal chips or filings are ideally of uniform size. They are cleaned thoroughly in alcohol. Chips are ideally a mixture of nickel and silver, but other conductive materials can be used. Ideally, the chamber is evacuated, but not necessarily.

Until 1902 the coherer was the only detector in wide use. It dropped out of use about 1912. Tesla must have regarded the coherer as a passably reliable sensitive device because he used it in his robot (radio-controlled) boat (patented 1898) and in his Colorado lightning-tracking experiments (1900).

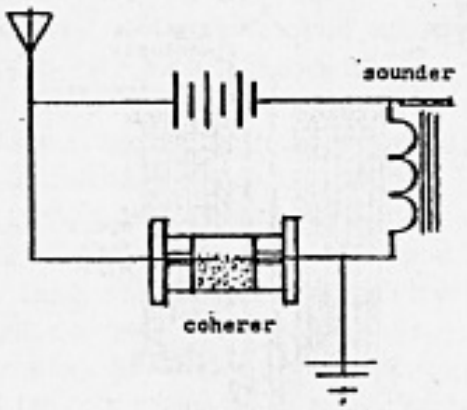
Tesla's detectors

Tesla explored the possibilities of many other sensitive devices. His patents show a rotating rectifier, a precursor to such static rectifying diodes as the crystal detector. Tesla replaced his rotating rectifier with a vacuum-tube diode. This is mentioned in the Colorado notes but there is no patent. I've seen mention of Tesla exhibiting, at the 1893 Chicago World's Fair, a vacuum-tube receiver for voice and music. This must have used for its detector a vacuum diode.

The idea of straining a device to near-conduction, as in the coherer, he applied to a diode vacuum tube and to semiconductors having thin-film dielectrics.

Another Tesla detector, limited to telegraphy, was visual. It used the deposit of a thin film on a glass surface. An iodine solution, upon being stimulated by a radio disturbance, releases a conductive haloid film onto the glass screen. Battery current, conducted through the film, destroys it, thus erasing the screen. A sort of telegraphic tv, this is a precursor of the liquid-crystal display.

Tesla's Colorado notes show a magnetic detector. It consists of a coil of many hundreds of turns of fine wire around glass-enclosed wires of soft iron which are magnetically stimulated by a disturbance. Marconi used a "magnetic detector" that worked on another principle. A pair of horseshoe magnets slowly revolved over an electro-magnet the windings of which were connected



coherer receiver

to earphones. This detector was the immediate successor to the coherer.

Tesla noticed that the megavolt streamers from his Colorado coils were extremely responsive to the slightest changes in etheric conditions and wondered how this phenomenon might be applied to the sensitive device. Later, working with high-voltage, high-frequency currents in vacuum, he discovered the "rotating brush." This is an eerie emanation, a brush discharge, from a spherical conductor exactly centered in a glass bulb. The device resembles the familiar plasma globes, but these contain gases. The result is different in a vacuum. The brush resolves into a rotating ray so sensitive that if you approach it from a few paces it will turn away from you. Tesla found that a small one-inch magnet "will affect it visibly at a distance of two meters, slowing down or accelerating the rotation according to how it's held relative to the brush." There is no information on how Tesla planned to harness the rotating brush as a sensitive device, but he wrote that it was "undoubtedly the most delicate wireless detector known."

Tesla's receivers

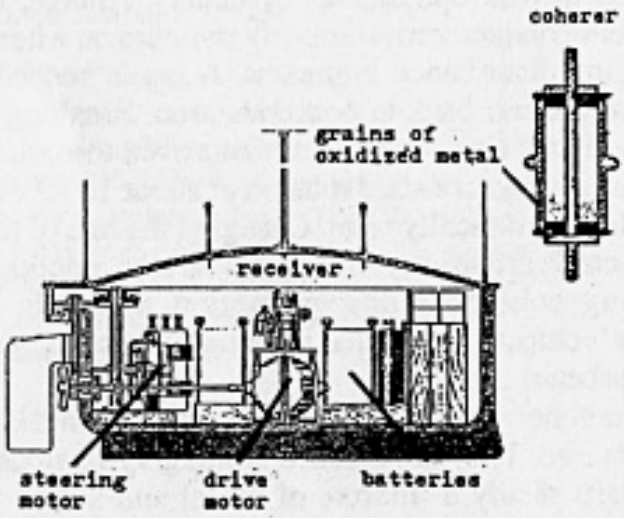
Over 50 different receiver circuits are to be found in Tesla's Colorado notes. These are various configurations of sensitive device, tuning coil, capacitor, rotary interrupter, and battery source. If early radio engineers had studied these notes (But how could they have since they were not published until 1978?), they would have found circuits that lay the foundation for two receivers which would dominate the history of radio: the regenerative, and the superhetrodyne.

Most of Tesla's receivers have one or more continuously moving parts, an offensive idea in this age of solid state. Tesla's coherer rotated, and so did his rectifying diode. Central to Tesla's receiver designs is another continously moving part, a rotary "break" or switch used to discharge the capacitor at the proper intervals. The break discharges the capacitor through a sounder. It is a device that magnifies effects.

All the moving parts notwithstanding, Tesla allows for semiconductors to do the job of the mechanical break. "The devices," he says in an 1898 patent, "may consist of merely two stationary electrodes separated by a feeble dielectric layer of minute thickness." Tesla's experience with spark gaps must have attuned him to the possibilities. He writes of thin insulative films serving as dielectrics. The patents offer no drawings or verbal detail. How far Tesla took these thin-film semiconductor ideas experimentally I do not know.

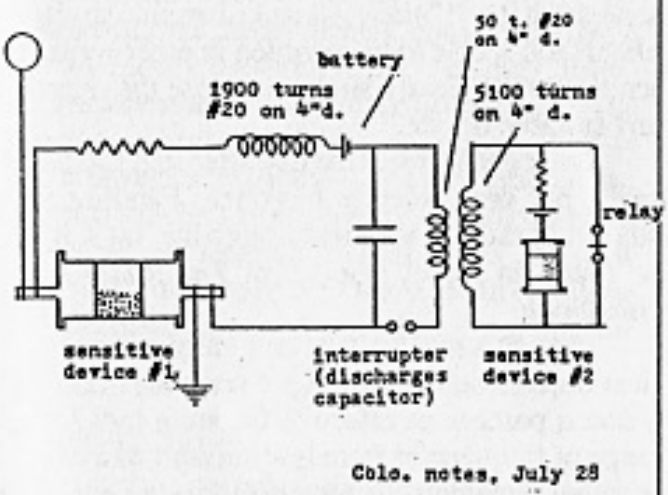
radio-free energy

Central to Tesla's receivers was the use of capacitors to store and release energy and to magnify effects: "However feeble or attenuated the impulses received, enough energy may be accumulated from them by storing up the energy of succeeding impulses for a sufficient interval of time to render the sudden liberation of it highly effective in operating a receiver." By "receiver" here



Patent No. 613,809 (1898)

Tesla's robot boat



Tesla's coherer receiver

Tesla means sounder. It probably took a fair amount of energy to drive the sounder, especially if what Tesla had in mind was the old magnetic click sounder used in wired telegraphy.

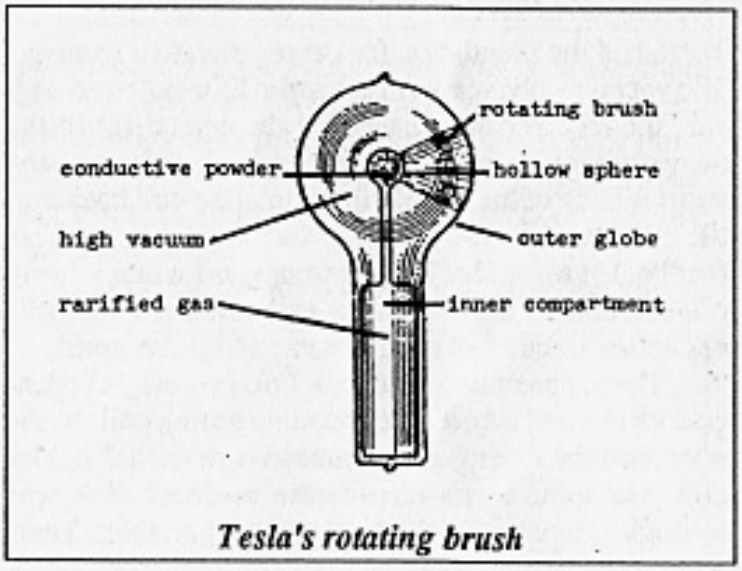
Tesla's free-energy patent (685,957) was filed at about the same time (1901) as a string of his radio receiver patents and is, in fact a kind of radio receiver. As in his radio receiving circuits Tesla is using precisely timed capacitive discharges to magnify effects. Timing is tuning and is critical whether receiving signals or collecting energy at levels sufficient to do work.

The capacitors suitable for energy applications, Tesla says, should be "of considerable electrostatic capacity," and the dielectrics made of "the best quality mica."

the crystal set

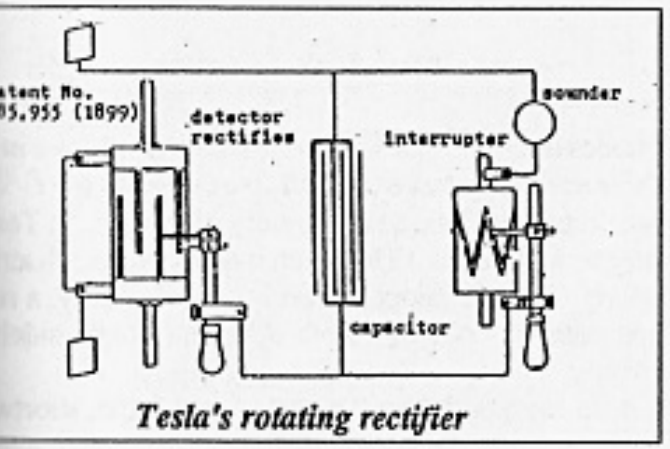
The simplest detector diode is the crystal, a sensitive device with a long and illustrious history in radio. It is not clear how close Tesla came to this kind of solid-state rectifying diode; he may have gone from the rotating rectifier to the vacuum diode unaware of the crystal principle, but I doubt it.

The crystal set is the simplest receiver in radio, and the tradition of crystal-set building persists even into this "high tech" era wedded to impressive complexity. You can build a crystal set using an inexpensive diode from Radio Shack. The traditional rock crystal with cat's whisker is still available from Antique Radio Supply, as is the high-impedence headset that enables you to listen to crystal and other elemental receivers without amplification. The cat's-whisker crystal was mass-produced in the Crystal Age enclosed in a glass envelope and with the cat's whisker welded to the active spot. Although germanium became the dominant rectifying material for diodes, similar detectors show up in the literature where the same rectification is accomplished with junction to less exotic materials: an acid solution, an electrolytic solution, a piece of strap iron. Soon after WWII there appeared a "foxhole" radio which used for its detector a safety pin and a razorblade of the no-longer-available blued-steel type. I built one, and it worked.

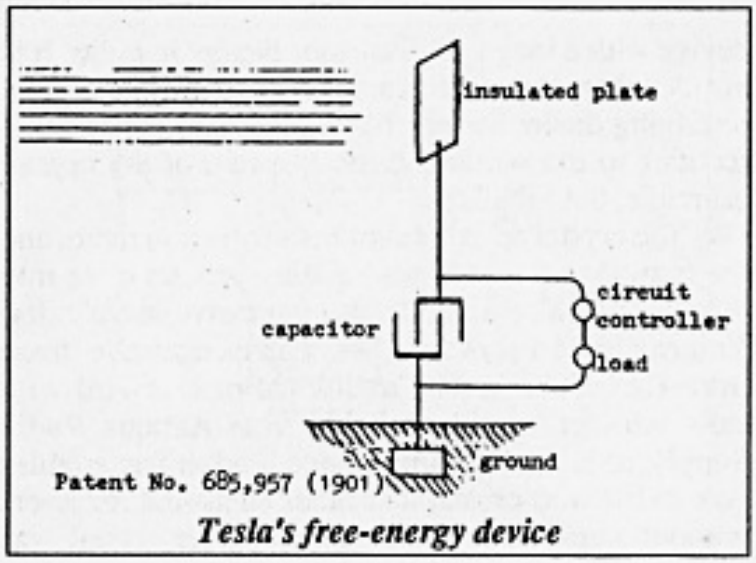


Tesla's rotating brush

The crystal set is the simplest receiver you can build. While a single tuning (tank) circuit might work in the country, in the city one strong station may overwhelm all others unless multiple tuning circuits are used. A crystal set with two or more tuned circuits is the simplest practical radio receiver.



Tesla's rotating rectifier

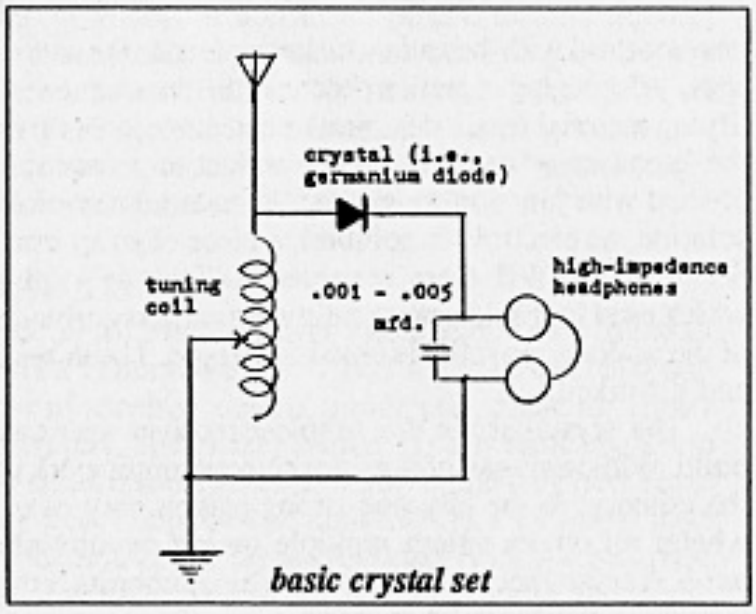


Tesla's free-energy device

the regenerative

Tesla laid the foundation for the regenerative receiver. The vacuum-tube version, credited to Edwin Armstrong, was the receiver that succeeded the crystal set in the development of radio. "Regenerative" refers to the recirculating of the signal vibrating in the coil back into the sensitive device so as to further excite it. This feedback is another of Tesla's strategies for magnifying effects, and he knew about it early on from the self-excitation circuits he used in some of his dynamos.

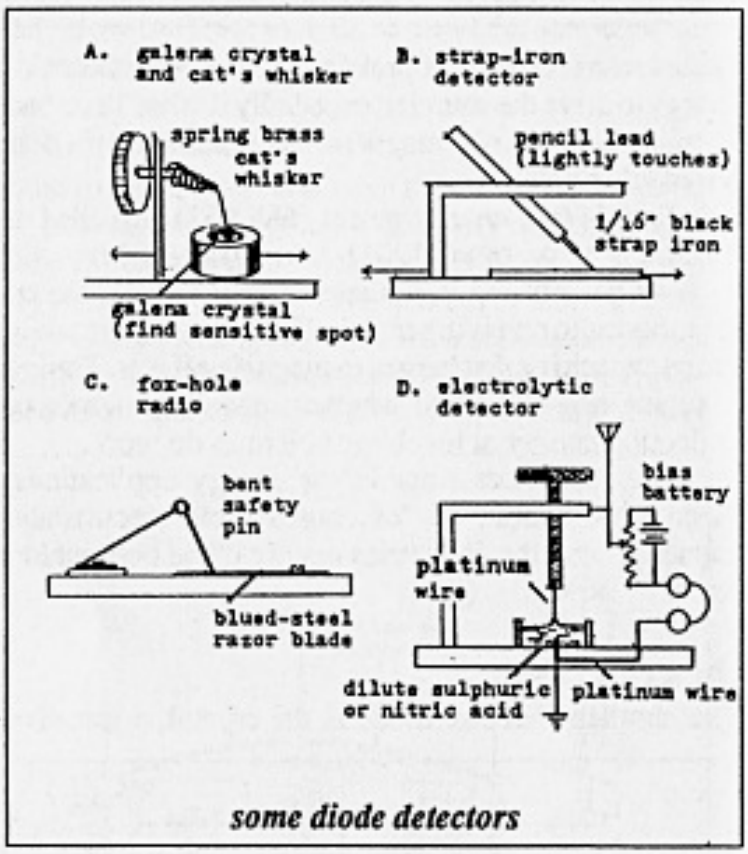
The regenerative feedback link in Tesla's regenerative is a coil adjacent to the main tuning coil. In the vacuum-tube regens this became known as the "tickler coil." In some regen circuits the feedback link was through a capacitor, which could be a variable. Tesla did not patent the regen but shows many circuit variations of the idea in his Colorado notes, where he observes that it had "many valuable uses since by its means effects too feeble to be recorded in other ways may be rendered sufficiently strong to cause the operation of any suitable device."



basic crystal set

The regen is one of the forgotten magical circuits of radio, but only recently forgotten. Familiar to every student of radio at least up through the '60's, it is not to be found in recent editions of *The Radio Amateurs Handbook*.

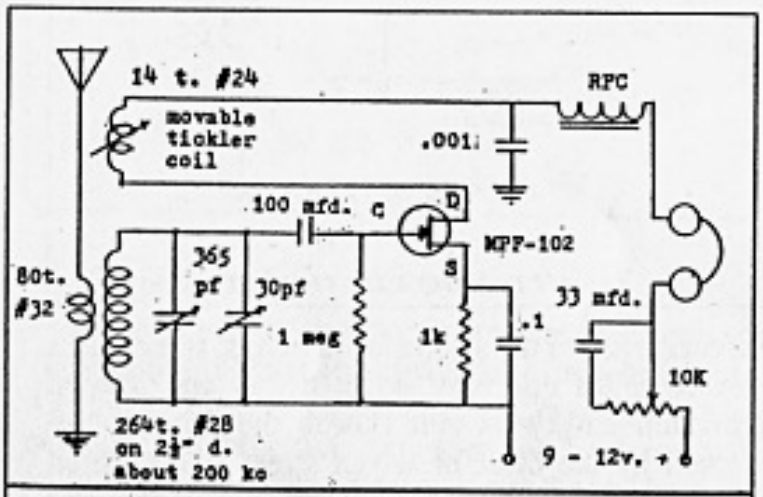
Though a regen often has a stage or two of amplification, an unamplified, single-stage regen having only a dozen parts is an effective listening tool for a wide range of frequencies from low through short wave. (As in other elemental receivers, high-impedence head phones are used. These differ from other phones in that there are many more turns of finer wire on the electromagnets, a technique to magnify effects, as in Tesla's magnetic detector.) The regen is sensitive and discriminating. As is, without any additional circuitry, a regen can receive code and both AM and single-sideband phone.

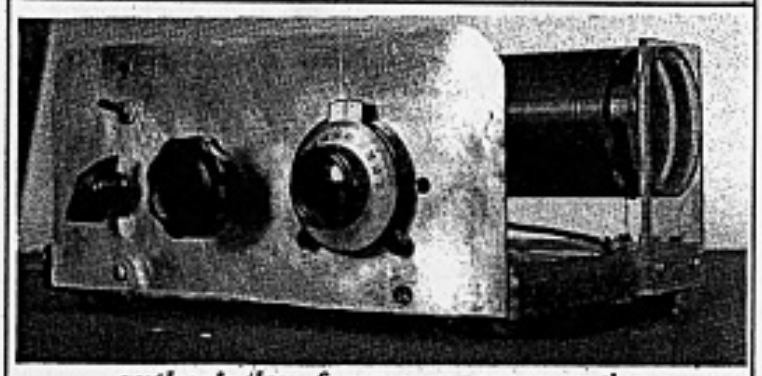


some diode detectors

In my youth I built a one-tube, 4-band, shortwave

delicate junctions and tenuous conductors within integrated circuits and other solid-state devices are particularly prone to vaporization. (Vacuum-tube devices are said to be ten-thousand times more resistant.) It's been speculated that a nuke exploded 200 miles above Nebraska would dud all unprotected solid-state circuitry in the continental United States. Particularly vulnerable are components connected to the power grid,

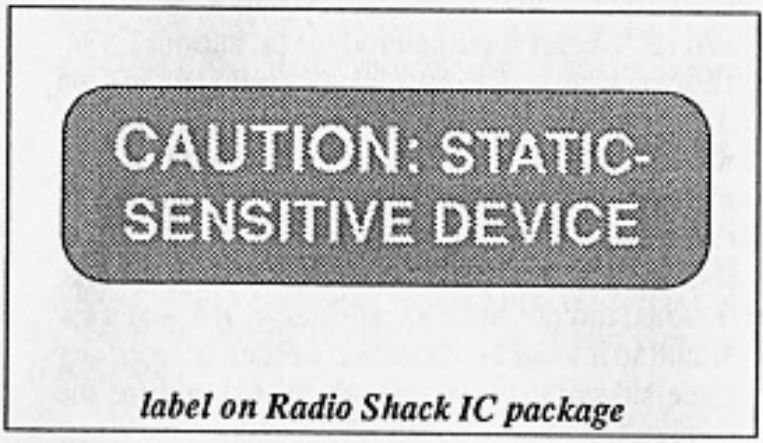




author's 'low-frequency' regenerative

to telephone lines, and to antennas. Magnetic memory could also be erased. While large institutions have been cued to this contingency and are moving ahead with the hardening of computer and communications facilities, the general public is largely oblivious to the fact that the entire "high tech" electronic culture is EMP-cancellable at a stroke.

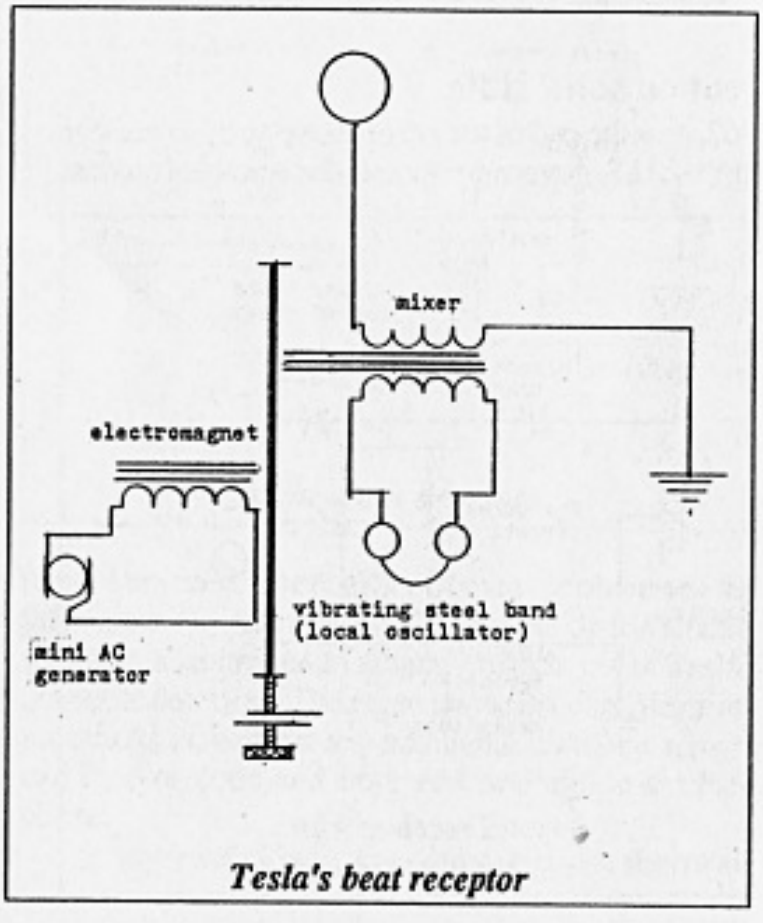
This same vulnerability of solid-state devices to shock makes them a headache for the builder experimenter. The ability to plug these little items into breadboards is a big step forward in convenience, but, when a circuit fails, the experimenter is left wondering whether his hook-up is flawed or has the IC or transistor blown due to excess heat in soldering, some miniscule excess of current or voltage, from reversed polarity, some



label on Radio Shack IC package

mini-EMP-like static discharge, or kickback from some related high-voltage component.

The same cheap mass production of transistors and IC's that has made possible the world of digital has also encouraged the corruption of the quality of electronic components across the board. Switches, pots, audio transformers, variable capacitors, once built with integrity have become cheaply made mini-junk, and this is often the only stuff readily available to experimenters. Parts suitable for transmitters, tesla coils, and other high-voltage, high-current work, like power transformers, heavy-duty wire-wound pots, chokes, high-watt



Tesla's beat receptor

resistors, transmitter variables, vacuum tubes, and insulators, must be obtained from surplus sources. For experimenters mini-junk electronics also means tiny, brittle, vexatious, finger-puncturing, eye-straining connection terminals where there used to be hefty lead wires or sturdy posts.

Miniaturization did not become an obsession until the 1950's and the advent of the miniature and "acorn" tubes. The fashion ultimately reduced the size of all components to the minimum, including coils. But formerly, the size of a coil was correlated with its power. "Note the difference in size," said an ad in an *Electrical Experimenter* magazine of 1917. The ad illustrated a 15,000-meter ham antenna-loading coil against a competitor's smaller counterpart. The advertised coil's diameter was 10 inches, its length 32. A typical Tesla receiving coil was 25 inches in diameter. Tesla built with rugged components and on a shameless scale.

for more information

Some coherer technology is to found in **Induction Coils** (Borderland). For Tesla's free-energy patent and other suppressed Tesla technology: **Tesla: The Lost Inventions** by George Trinkaus (High Voltage Press). For crystal set projects **Radios That Work for Free** by K. E. Edwards (Lindsay). **EMP** is from Rex Research. **Antique Radio Supply** is a source of crystal detectors, tubes, variable caps, and more. (P.O. Box 27468, Tempe, AZ 85285). **All Electronics** for all sorts of experimenter stuff. (P.O. Box 567, Van Nuys, CA 91408). A good radio surplus source: **R5D3** (Portland, OR, 503-513-0410).

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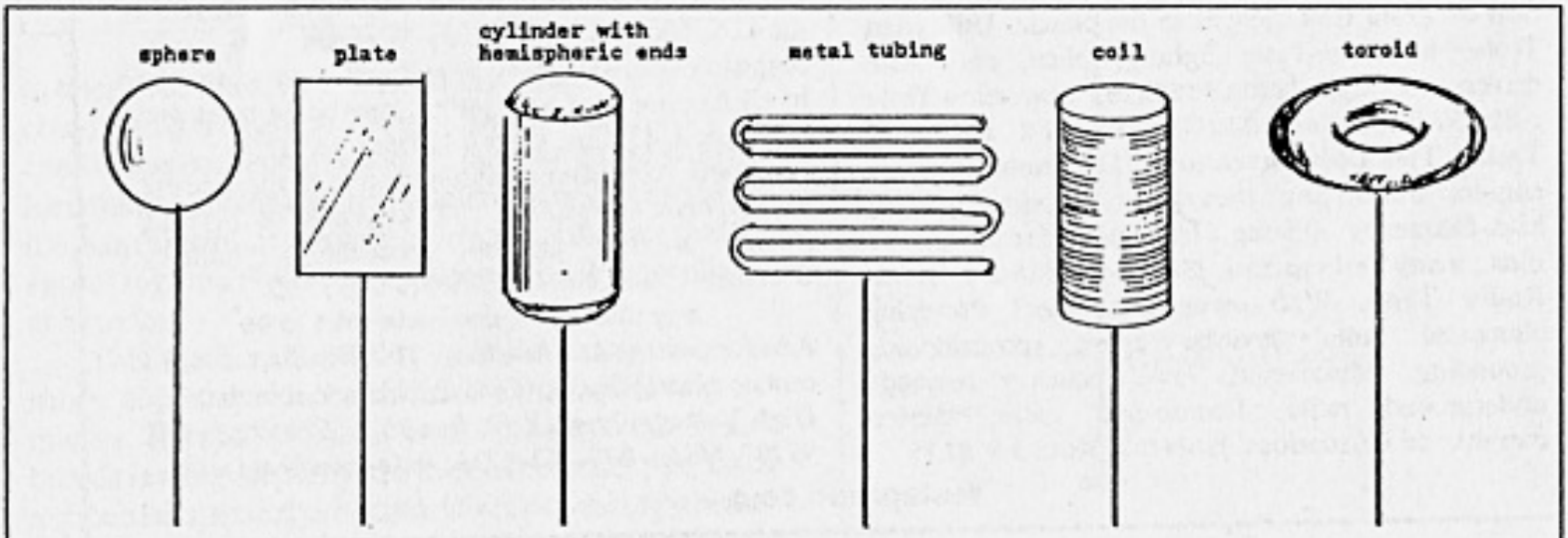
6. Aerial Capacity

That ball sticking up in the air that is so symbolic of Tesla's radio: What is it? Some sort of antenna? Actually, Tesla never referred to it as an antenna but as an "aerial" or "air capacity" or as an "elevated capacity." Tesla did not see the elevated ball as a radiator, which is how the transmitting antenna of conventional Hertzian radio is construed. The aerial capacity corresponds to the terminal capacitor of a tesla coil. Tesla said that in radio the aerial capacity "heightened the effect" of what is essentially a grounded system. Electrically, in transmitting, it appears to provide a capacitive leverage against which to pump ground. The ball shape also holds high voltage, minimizing coronal discharge and loss.

The ball aerial appears on Tesla's receivers as well as on his transmitters. Tesla understood that a long wire (as in a long-wire antenna) had capacity but he believed the sphere was the efficient geometry. "By using a body of considerable surface...better results are obtained than a wire leading to a height alone... The system is more economical in providing an electrical vibration in the ground." This would be especially true at low frequencies that would require a wire of inordinate length. Tesla's Colorado transmitter when operating at 60 kc would have required a half-wave wire antenna 2500 meters long if modern antenna conventions had been observed.

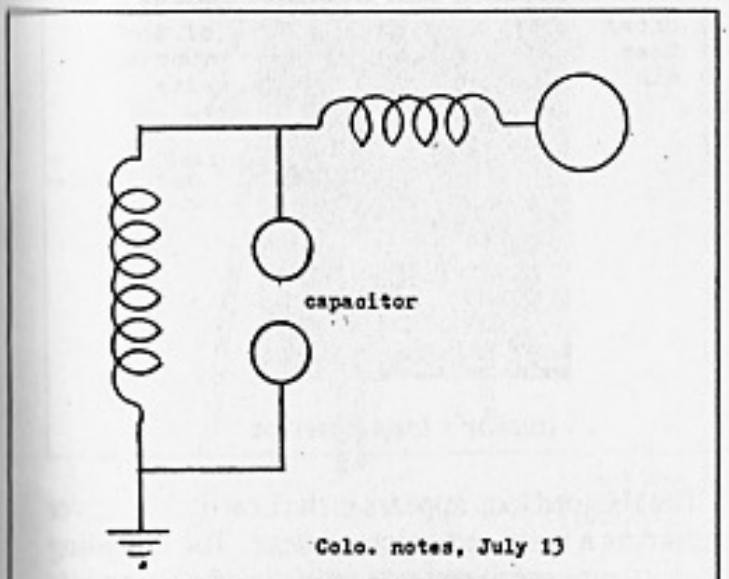
Tesla also believed that the idea of polarizing, or putting into parallel, transmitting and receiving antennas was nonsense. On his Colorado magnifying trans-



aerial capacity geometries

mitter, Tesla used a hollow copper sphere only 30 inches in diameter. It was thickly coated with rubber insulation. Insulated or not, the ball terminal reduces to a minimum the problem of streamers breaking out at high electrical pressures, since those jump more readily from angular surfaces. Tesla experimented extensively with the effect of the ball's height. An increase in height caused an increase in the effective capacity of the ball, Tesla discovered. (However, of Hertzian radio, Tesla said, "The actions at a distance cannot be proportionate to the height of the antenna or the current in same.")

The ball worked for Tesla but so did other geometries. In Colorado Tesla experimented with a structure of iron pipes as an aerial capacity. He said the aerial



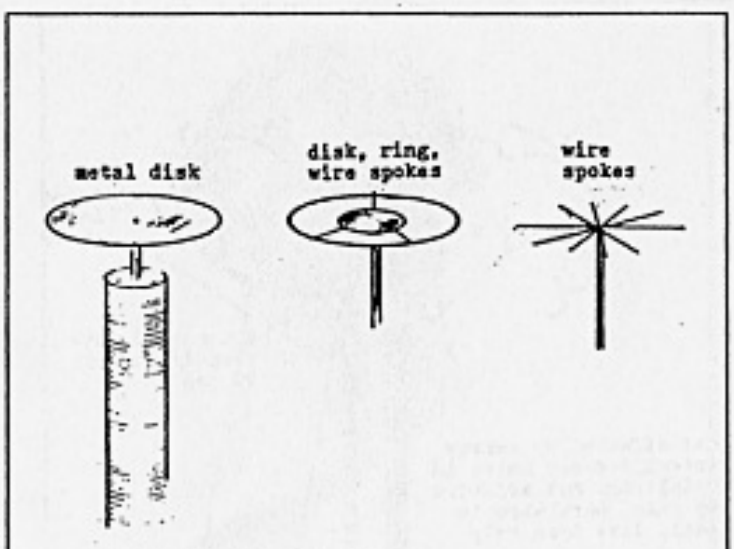
Tesla's opposing-ball capacitor

capacity could be a cylinder with hemispheric ends, or it could be a toroid. Tesla suggested that a coil of insulated wire put aloft would suffice. He said any hollow vessel, like a ball, could be filled with a gas like hydrogen at low pressure for better effect. Some of Tesla's receiver schematics show the aerial capacity as a simple metal plate.

The ball capacitor shows up in other Tesla circuits besides aerial, consisting of a capacitor of two opposing hollow balls.

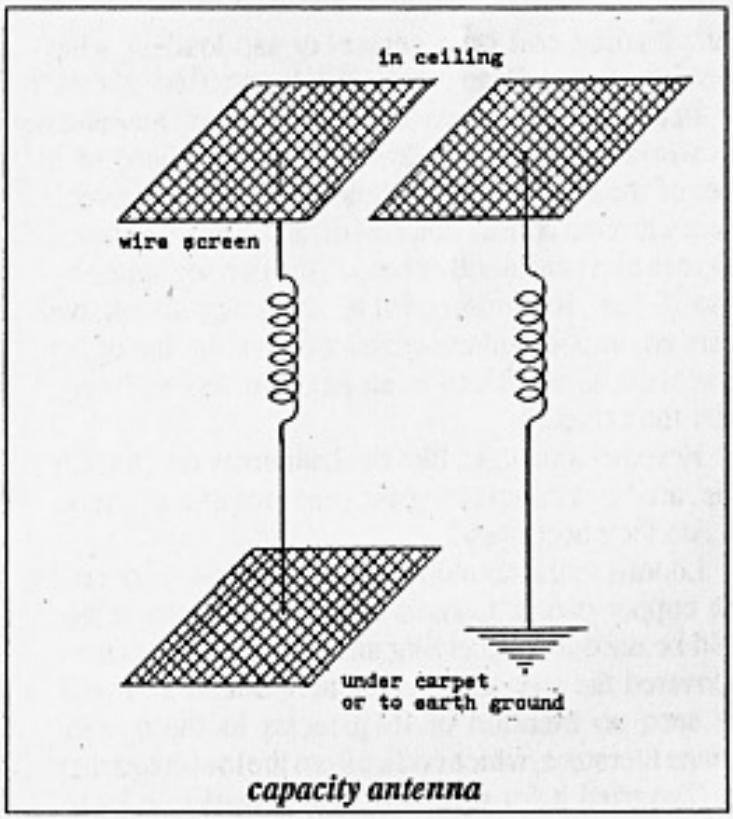
capacitive antennas

The "capacitive hat" appears as an occasional element in modern antenna design. Although the texts explain it as something that "improves radiating efficiency," it's still in the nomenclature as a "capacitive hat." Capaci-

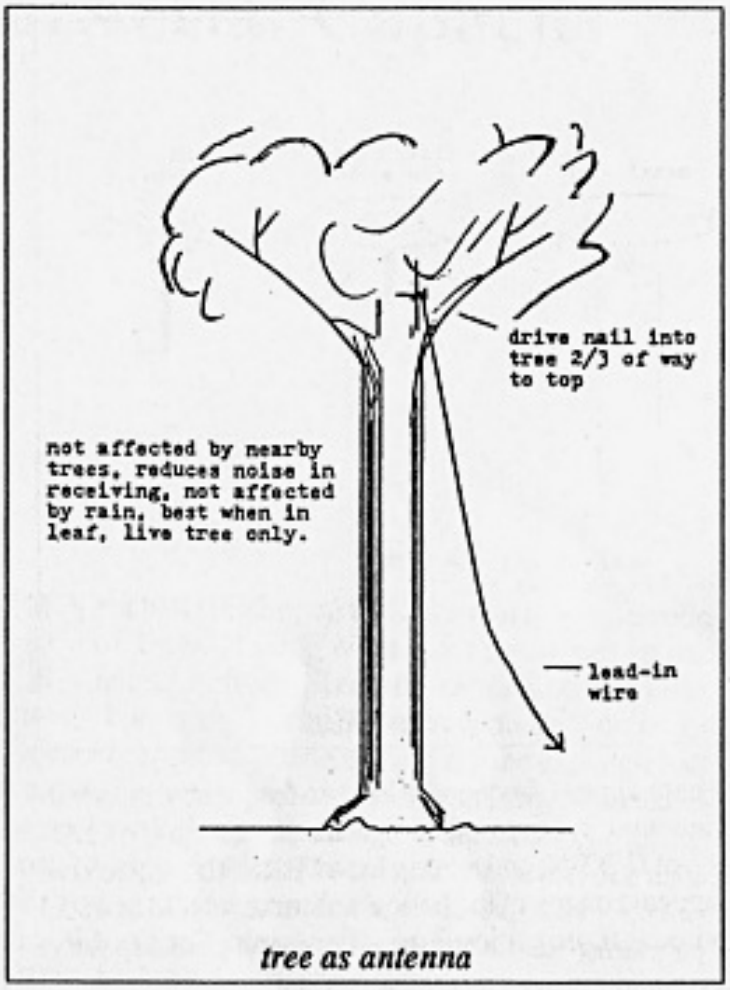


capacitive hats

tive hats appear frequently in low-frequency radio: in the antenna systems of navigational beacons, of LORAN, of GWEN, and among LowFERs. The capacitive hat appears on top of the helical antenna, which, as a coil of wire aloft, might itself qualify as an aerial capacity.



capacity antenna


drive nail into tree 2/3 of way to top
not affected by nearby trees, reduces noise in receiving, not affected by rain, best when in leaf, live tree only.
lead-in wire

tree as antenna

Is the loading coil on a center- or top-loading whip "seen" as an aerial capacity?

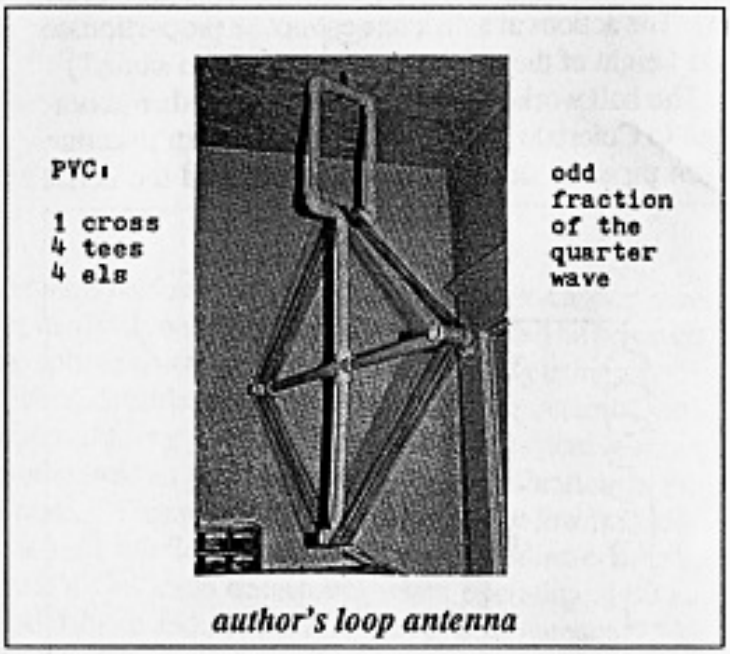
In the radio literature of the 1920's there are references to a "capacitive antenna." This consisted of a sheet of metal or a wire screen aloft or, alternatively, where a ground connection was distant, a sheet of metal or screen aloft and another below, the two separated by 10 to 15 feet. Recommended as an indoor alternative where an outdoor antenna cannot be put up, the upper element could be placed in an attic, the lower, if any, under the carpet.

Hertzian antennas, like the ham array and the CB whip, are flags announcing the presence of a transmitter. Are they necessary?

Loomis sent kites aloft as aerials; they were covered with copper gauze. Loomis also observed that a tree could be used as a receiving antenna, and others have discovered the tree as a transmitting antenna as well. I've seen no mention of frequencies in the tree-as-antenna literature, which comes from the low-frequency era. (I've tried it for receiving, and it works on long-, medium-, and shortwave bands.) Does the transmitter or receiver "see" the tree as a Tesla-style aerial capacity?

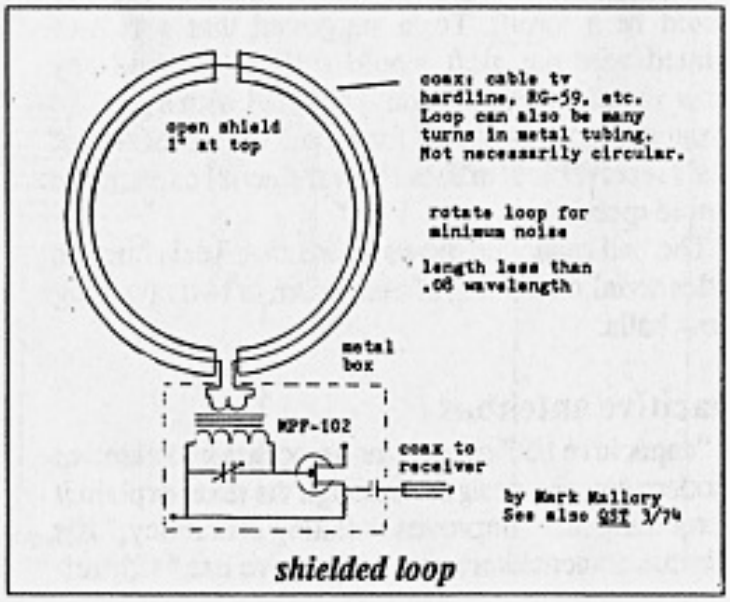
loops

Loop antennas abound in radio and suggest Tesla's elevated-coil idea. You can easily build your own using PVC tubing for the structure. For strength, use one-inch schedule 40 tubing instead of the 1/2 inch I used (photo).



author's loop antenna

The shielded loop appears in the LowFER receiver literature as a noise-reduction strategy. The shielding excludes the magnetic component of disturbances while the loop inside responds only to the electrostatic, ac-

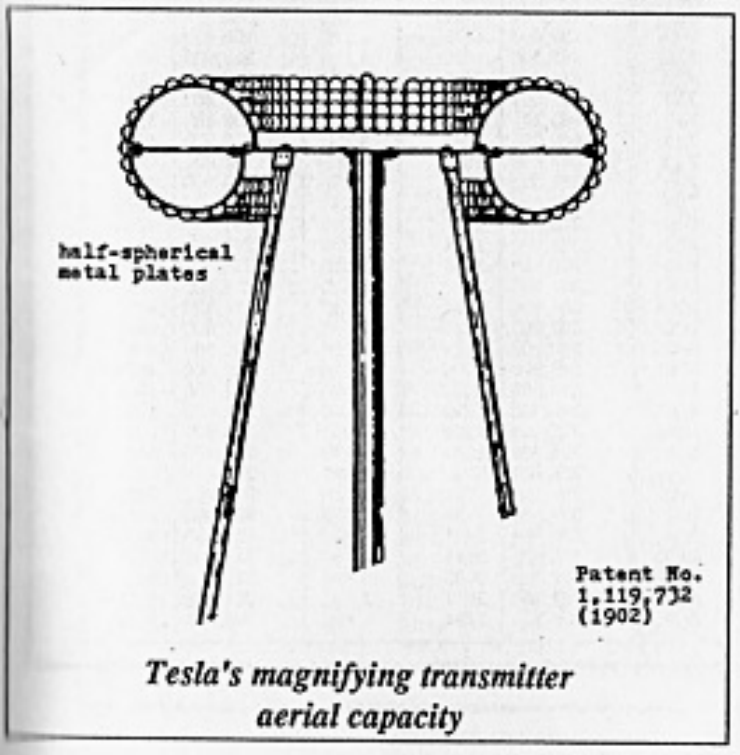

coax: cable tv hardline, RG-59, etc. Loop can also be many turns in metal tubing. Not necessarily circular.
open shield 1" at top
rotate loop for minimum noise
length less than .06 wavelength
metal box
MPF-102
coax to receiver
by Mark Mallory
See also QST 3/74

shielded loop

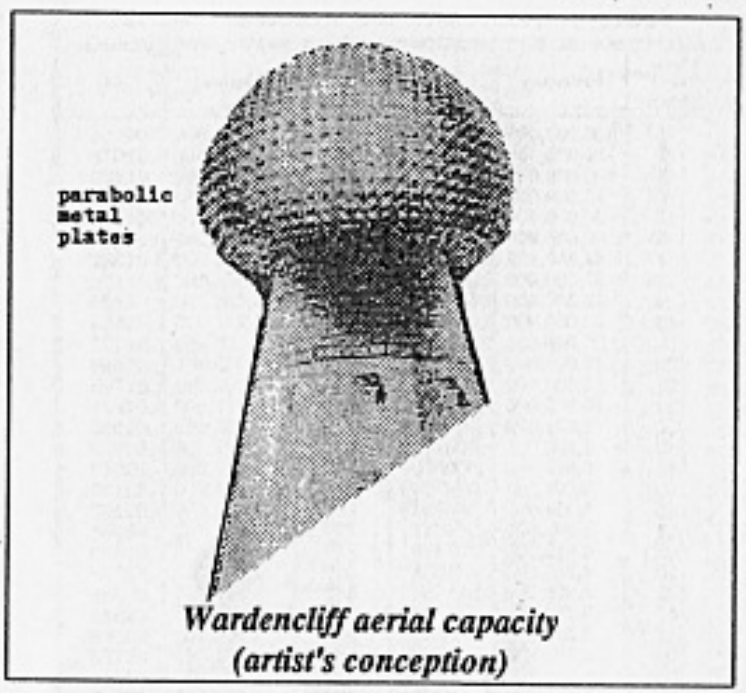
cording to the literature. A preamp is a good idea with any loop.

studded mushroom

Tesla's magnifying transmitter patent shows a toroid-shaped aerial capacity. It is studded with half-spherical metal plates, presumably to enlarge the surface without increasing by much the bulk. The ultimate Tesla aerial capacity is the studded mushroom that topped his Wardencliff tower. Its diameter was 68 feet. The studding may have been parabolic rather than strictly hemispherical. There is not much information about the tower, and Tesla's reasoning behind the strange geometry is not fully understood.



Tesla's magnifying transmitter aerial capacity



Wardencliff aerial capacity (artist's conception)

The notion of aerial capacity has little currency outside of Tesla-land. What would antennas be like if they were reinvented, not as senders and receivers of Hertzian radiation, but as aerial capacitors?

for more information

Electric Spacecraft Journal, ed. by Charles Yost, has some interesting speculations on Wardencliff's terminal. (P.O. Box 18387, Ashville, NC 28814). **Trees as Antennas** (Rex Research).

WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT

Wavelength Meters	Frequency	LC	Wavelength Meters	Frequency	LC
1	300,000,000	.0000003	190	1,579,000	.01016
2	150,000,000	.0000011	195	1,538,000	.01071
3	100,000,000	.0000025	200	1,500,000	.01126
4	75,000,000	.0000045	205	1,463,000	.01183
5	60,000,000	.0000070	210	1,429,000	.01241
6	50,000,000	.0000101	215	1,395,000	.01301
7	42,860,000	.0000138	220	1,364,000	.01362
8	37,500,000	.0000180	225	1,333,000	.01425
9	33,333,000	.0000228	230	1,304,000	.01489
10	30,000,000	.0000282	235	1,277,000	.01555
15	20,000,000	.0000634	240	1,250,000	.01622
20	15,000,000	.0001126	245	1,225,000	.01690
25	12,000,000	.0001760	250	1,200,000	.01760
30	10,000,000	.0002533	255	1,177,000	.01831
35	8,571,000	.0003448	260	1,154,000	.01903
40	7,500,000	.0004503	265	1,132,000	.01977
45	6,667,000	.0005700	270	1,111,000	.02052
50	6,000,000	.0007039	275	1,091,000	.02129
55	5,454,000	.0008519	280	1,071,000	.02207
60	5,000,000	.001014	290	1,034,500	.02366
65	4,615,000	.001188	295	1,017,000	.02450
70	4,286,000	.001378	300	1,000,000	.02533
75	4,000,000	.001583	310	967,700	.02705
80	3,750,000	.001801	320	937,500	.02883
85	3,529,000	.002034	330	909,100	.03066
90	3,333,000	.002280	340	882,400	.03255
95	3,158,000	.002541	350	857,100	.03448
100	3,000,000	.002816	360	833,300	.03648
105	2,857,000	.003105	370	810,800	.03854
110	2,727,000	.003404	380	789,500	.04065
115	2,609,000	.003721	390	769,200	.04277
120	2,500,000	.004052	400	750,000	.04503
125	2,400,000	.004397	410	731,700	.04733
130	2,308,000	.004757	420	714,300	.04966
135	2,222,000	.005130	430	697,700	.05204
140	2,144,000	.005518	440	681,800	.05446
145	2,069,000	.005919	450	666,700	.05700
150	2,000,000	.006335	460	652,200	.05960
155	1,935,000	.006760	470	638,300	.06219
160	1,875,000	.007204	480	625,000	.06485
165	1,818,000	.007662	490	612,200	.06759
170	1,765,000	.008134	500	600,000	.07039
175	1,714,000	.008620	510	588,200	.07327
180	1,667,000	.009120	520	576,900	.07606
185	1,622,000	.009634	530	566,000	.07905

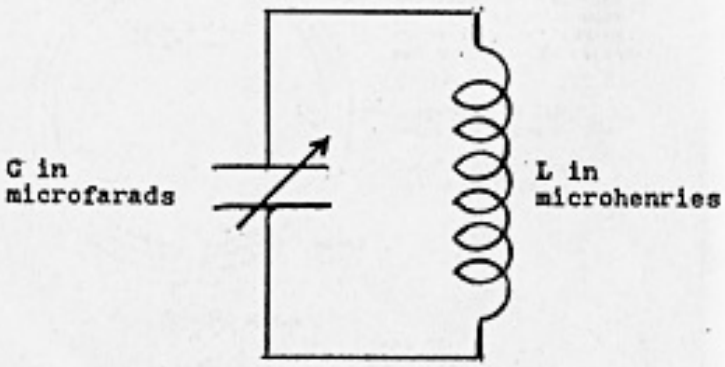
WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT—(Continued)

Wavelength Meters	Frequency	LC	Wavelength Meters	Frequency	LC
540	555,600	.08208	990	303,100	.2759
550	545,400	.08519	1,000	300,000	.2816
560	535,700	.08836	1,010	297,000	.2870
570	526,300	.09139	1,020	294,100	.2927
580	517,200	.09467	1,030	291,300	.2986
590	508,500	.09801	1,040	288,400	.3045
600	500,000	.1014	1,050	285,700	.3105
610	491,800	.1047	1,060	283,600	.3161
620	483,900	.1082	1,070	280,400	.3222
630	476,200	.1117	1,080	277,800	.3283
640	468,700	.1154	1,090	275,200	.3345
650	461,500	.1188	1,100	272,700	.3404
660	454,500	.1225	1,110	270,300	.3467
670	447,800	.1263	1,120	267,900	.3531
680	441,200	.1302	1,130	265,500	.3595
690	434,800	.1341	1,140	263,100	.3660
700	428,600	.1378	1,150	260,900	.3721
710	422,500	.1419	1,160	258,600	.3787
720	416,700	.1459	1,170	256,400	.3853
730	411,000	.1501	1,180	254,200	.3921
740	405,400	.1540	1,190	252,100	.3988
750	400,000	.1583	1,200	250,000	.4052
760	394,800	.1626	1,210	247,900	.4121
770	389,600	.1668	1,220	245,900	.4190
780	384,600	.1712	1,230	243,900	.4260
790	379,800	.1756	1,240	241,900	.4326
800	375,000	.1801	1,250	240,000	.4397
810	370,400	.1847	1,260	238,100	.4469
820	365,900	.1893	1,270	236,200	.4541
830	361,400	.1941	1,280	234,400	.4610
840	357,100	.1985	1,290	232,600	.4683
850	352,900	.2034	1,300	230,800	.4757
860	348,800	.2082	1,310	229,000	.4831
870	344,800	.2132	1,320	227,300	.4906
880	340,900	.2179	1,330	225,600	.4978
890	337,100	.2229	1,340	223,900	.5053
900	333,300	.2280	1,350	222,200	.5130
910	329,700	.2332	1,360	220,600	.5208
920	326,100	.2381	1,370	218,900	.5281
930	322,600	.2434	1,380	217,400	.5359
940	319,100	.2487	1,390	215,800	.5438
950	315,900	.2541	1,400	214,300	.5518
960	312,500	.2595	1,410	212,800	.5598
970	309,300	.2647	1,420	211,300	.5674
980	306,100	.2704	1,430	209,800	.5755

tank tables

To calculate the appropriate values for any tank coil and capacitor to resonate at a particular frequency, I find these tables from a 1928 technical-school text clear and useful.. They are also useful for engineering a tesla coil. The column headed "LC" contains numbers representing the "oscillation constant." This is the number you get by multiplying the capacitance in microfarads by the inductance in microhenries. If you know one value, you can get the other by division. The frequency in column two is in cycles; lop off three zeros for kilocycles. See pages 21 –22.

Usually the variable capacitor will be the known and the coil the unknown. Variables are rated in picofarads. Move the decimal point six places to the left to get microfarads.



WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT—(Continued)

Wave-length Meters	Frequency	LC	Wave-length Meters	Frequency	LC
1,440	208,300	.5837	1,890	158,700	1.006
1,450	205,900	.5919	1,900	157,900	1.016
1,460	205,500	.5998	1,910	157,100	1.027
1,470	204,100	.6081	1,920	156,300	1.038
1,480	202,700	.6165	1,930	155,400	1.049
1,490	201,300	.6250	1,940	154,600	1.060
1,500	200,000	.6335	1,950	153,800	1.071
1,510	198,700	.6416	1,960	153,100	1.081
1,520	197,400	.6502	1,970	152,300	1.092
1,530	196,100	.6590	1,980	151,500	1.104
1,540	194,800	.6677	1,990	150,800	1.115
1,550	193,600	.6760	2,000	150,000	1.126
1,560	192,300	.6849	2,050	146,300	1.183
1,570	191,100	.6938	2,100	142,900	1.241
1,580	189,900	.7028	2,150	139,500	1.301
1,590	188,700	.7118	2,200	136,400	1.362
1,600	187,500	.7204	2,250	133,300	1.425
1,610	186,300	.7295	2,300	130,400	1.489
1,620	185,200	.7387	2,350	127,700	1.555
1,630	184,100	.7480	2,400	125,000	1.622
1,640	182,900	.7573	2,450	122,500	1.690
1,650	181,800	.7662	2,500	119,000	1.760
1,660	180,700	.7756	2,550	117,700	1.831
1,670	179,600	.7852	2,600	115,400	1.903
1,680	178,800	.7946	2,650	113,200	1.977
1,690	177,500	.8037	2,700	111,100	2.052
1,700	176,500	.8134	2,750	109,100	2.129
1,710	175,400	.8231	2,800	107,100	2.207
1,720	174,400	.8329	2,850	105,300	2.287
1,730	173,400	.8422	2,900	103,500	2.366
1,740	172,400	.8520	2,950	101,700	2.450
1,750	171,400	.8620	3,000	100,000	2.533
1,760	170,500	.8720	3,100	96,770	2.705
1,770	169,400	.8821	3,200	93,750	2.883
1,780	168,500	.8916	3,300	90,910	3.066
1,790	167,600	.9018	3,400	88,240	3.255
1,800	166,700	.9120	3,500	85,910	3.448
1,810	165,700	.9223	3,600	83,330	3.648
1,820	164,800	.9327	3,700	81,080	3.854
1,830	163,900	.9425	3,800	78,950	4.065
1,840	163,000	.9530	3,900	76,920	4.277
1,850	162,200	.9634	4,000	75,000	4.503
1,860	161,300	.9741	4,100	73,170	4.733
1,870	160,400	.9841	4,200	71,430	4.966
1,880	159,600	.9948	4,300	69,770	5.204

WAVELENGTH, FREQUENCY, AND OSCILLATION CONSTANT—(Continued)

Wave-length Meters	Frequency	LC	Wave-length Meters	Frequency	LC
4,400	68,180	5.446	8,800	34,090	21.79
4,500	66,670	5.700	8,900	33,710	22.20
4,600	65,220	5.960	9,000	33,330	22.80
4,700	63,830	6.219	9,100	32,970	23.32
4,800	62,500	6.485	9,200	32,610	23.81
4,900	61,220	6.759	9,300	32,260	24.34
5,000	60,000	7.039	9,400	31,910	24.87
5,100	58,820	7.327	9,500	31,590	25.41
5,200	57,690	7.606	9,600	31,250	25.95
5,300	56,600	7.905	9,700	30,930	26.47
5,400	55,560	8.208	9,800	30,610	27.04
5,500	54,550	8.519	9,900	30,310	27.59
5,600	53,570	8.835	10,000	30,000	28.16
5,700	52,630	9.139	10,500	28,570	31.05
5,800	51,720	9.467	11,000	27,270	34.04
5,900	50.850	9.801	11,500	26,090	37.21
6,000	50,000	10.14	12,000	25,000	40.52
6,100	49,180	10.47	12,500	24,000	43.97
6,200	48,550	10.82	13,000	23,080	47.57
6,300	47,620	11.17	13,500	22,220	51.30
6,400	46,870	11.54	14,000	21,440	55.18
6,500	46,150	11.88	14,500	20,690	59.19
6,600	45,450	12.25	15,000	20,000	63.35
6,700	44,780	12.63	15,500	19,350	67.60
6,800	44,120	13.02	16,000	18,750	72.04
6,900	43,480	13.41	16,500	18,180	76.62
7,000	42,860	13.78	17,000	17,650	81.34
7,100	42,250	14.19	17,500	17,140	86.20
7,200	41,670	14.59	18,000	16,670	91.20
7,300	41,100	15.01	18,500	16,220	96.34
7,400	40,540	15.40	19,000	15,790	101.64
7,500	40,000	15.83	19,500	15,380	107.06
7,600	39,470	16.26	20,000	15,000	112.56
7,700	38,960	16.68	21,000	14,290	124.12
7,800	38,460	17.14	22,000	13,640	136.24
7,900	37,980	17.56	23,000	13,040	148.93
8,000	37,500	18.01	24,000	12,500	162.18
8,100	37,040	18.47	25,000	12,000	175.97
8,200	36,590	18.93	26,000	11,540	190.26
8,300	36,140	19.41	27,000	11,110	205.20
8,400	35,710	19.85	28,000	10,710	220.70
8,500	35,290	20.34	29,000	10,350	236.63
8,600	34,880	20.82	30,000	10,000	253.32
8,700	34,480	21.32			

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